PUBLIC ROADS

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BUREAU OF PUBLIC ROADS

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POTOMAC RIVER FLOOD NEAR WASHINGTON, D. C., MAY, 1924

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A GENERAL FORMULA FOR WATERWAYS[1]

Reported by C. S. JARVIS, Associate Highway Engineer, U. S. Bureau of Public Roads

IN ENDEAVORING to design economical and safe bridges and similar structures the adequacy of which depends upon their proper adjustment to the flood flows of streams, the engineer is confronted with a maze of factors influencing the problem—scores of formulas and tables of data, hundreds of examples that serve as warnings, and thousands that appear satisfactory. Where records concerning the stream flow are lacking, he must rely on a study of the watershed and channel, the alluvial bars and embankments, the drift lodged along canyon walls and in crevices, and the indefinite memories of observers. In general, he will be unable to reconcile the data thus gathered; and then remains the question of assigning proper weights to various fragments of evidence.

Following such deductions, an important western railroad company located nearly 100 miles of line along a valley floor, safely above the reach of assumed maximum floods, only to experience its destruction within a few years. It was rebuilt on a higher line that would be safe against three or four times the maximum flow originally assumed. Similarly, various highway structures on Federal-aid projects regarded as entirely adequate have proved able to carry only a small part of torrential floods that have visited them.

In the course of his work in connection with the design of structures on Federal-aid road projects the writer has been impressed by the radical revisions required in waterways proportioned in accordance with the best available data and formulas. Repeatedly he has seen the capacity of channels believed to be more than ample exceeded by the floods that have followed severe summer storms; and he has been especially impressed by the variety of the indications of the various well-known waterway formulas and the narrow scope of their adaptability. In the hope of deriving a new expression capable of expansion to cover the entire range of watershed areas and conditions, he determined to plat on a single chart the best obtainable records of flood flows in relation to the area drained to ascertain the relation of the various common expressions to the data thus charted, and, if these were found to be lacking in agreement, to develop, if possible, a new and more adequate expression. At the start he had no preference for any one formula.

OVER A THOUSAND FLOOD RATES CHARTED

More than a thousand maximum flood rates were selected from the great mass of available data, fully three times that number, to represent the entire possible range of drainage areas and volumes of discharge. These observations were platted with q, the yield in second-feet per square mile, as ordinates and M, the drainage area in square miles, as abscissas, and on the same chart the graphical curves of the standard run-off formulas were superimposed so as to bring out the relation of each expression to the field of use. As originally reported in a paper entitled "Flood Flow Characteristics," published in the Proceedings of the American Society of Civil Engineers, December, 1924, this process brought forth a modification of the Myers formula with a coefficient varied according to a decimal scale as the simplest and most reliable and the only one capable of convenient extension over the entire scope of practice.

The original Myers formula, published in 1879, was the first American waterway expression. It employed the square root of the drainage area in acres and applied to this factor as a multiplier a coefficient ranging from 1 to 4 according to the surface condition to represent the area of waterway required in square feet. If a be chosen to represent the area of waterway in square feet, A the drainage area in acres, and C the coefficient depending upon the surface condition, the original form of the formula may be rendered as,

$$a = C\sqrt{A}$$

If the drainage area, A, in acres be converted into square miles, M, and the velocity of water through the waterway, V, be assumed at 10 feet per second, the discharge in cubic feet, Q, may be represented as—

$$Q = aV = 10C\sqrt{A} = 10\times 25.3C\sqrt{\frac{A}{640}} = 10\times 25.3C\sqrt{M}$$
$$= 250C\sqrt{M} \text{ (approx.)}$$

The claims regarding the wide application of the Myers formula brought forth the criticism of the late A. M. Wellington, who had no faith in such a device. His counterproposal was to make an intelligent estimate of the waterway required and then prescribe double this area for drainage structures. But, apparently, the "intelligent estimate" must depend upon some scale of comparison, whether it be tabular data, formulas, or field observations and experience; and while none of these can take the place of mature judgment, they are regarded as guides and controls, as later recognized by Mr. Wellington.

Since the development of the original Myers formula several others have been devised upon the basis of conditions observed in particular locations, among them those of Fanning, Talbot, Kuichling, Murphy, McMath, and a number of others.

Reducing the better known of these expressions to the same form—the form to which the original Myers formula has been reduced above—they may be expressed as follows:

Myers: $Q = 250\ C\sqrt{M}$

Fanning: $Q = 200\ \sqrt[6]{M^5}$

Talbot: $Q = 127\ C\sqrt[4]{M^3}$

McMath: $Q = 174\ C\sqrt[5]{M^4}$

The values of q, as derived from these and other formulas using the ordinary values of C, are plotted in Figure 1 against the corresponding values of M. Superimposed upon these are selected maximum flood flow data representative of the entire mass of data collected.

[1] See also the paper by the writer entitled "Flood Flow Characteristics," Proc. Am. Soc. Civ. Engrs., December, 1924; and discussions in subsequent issues of the same publication to December, 1925.

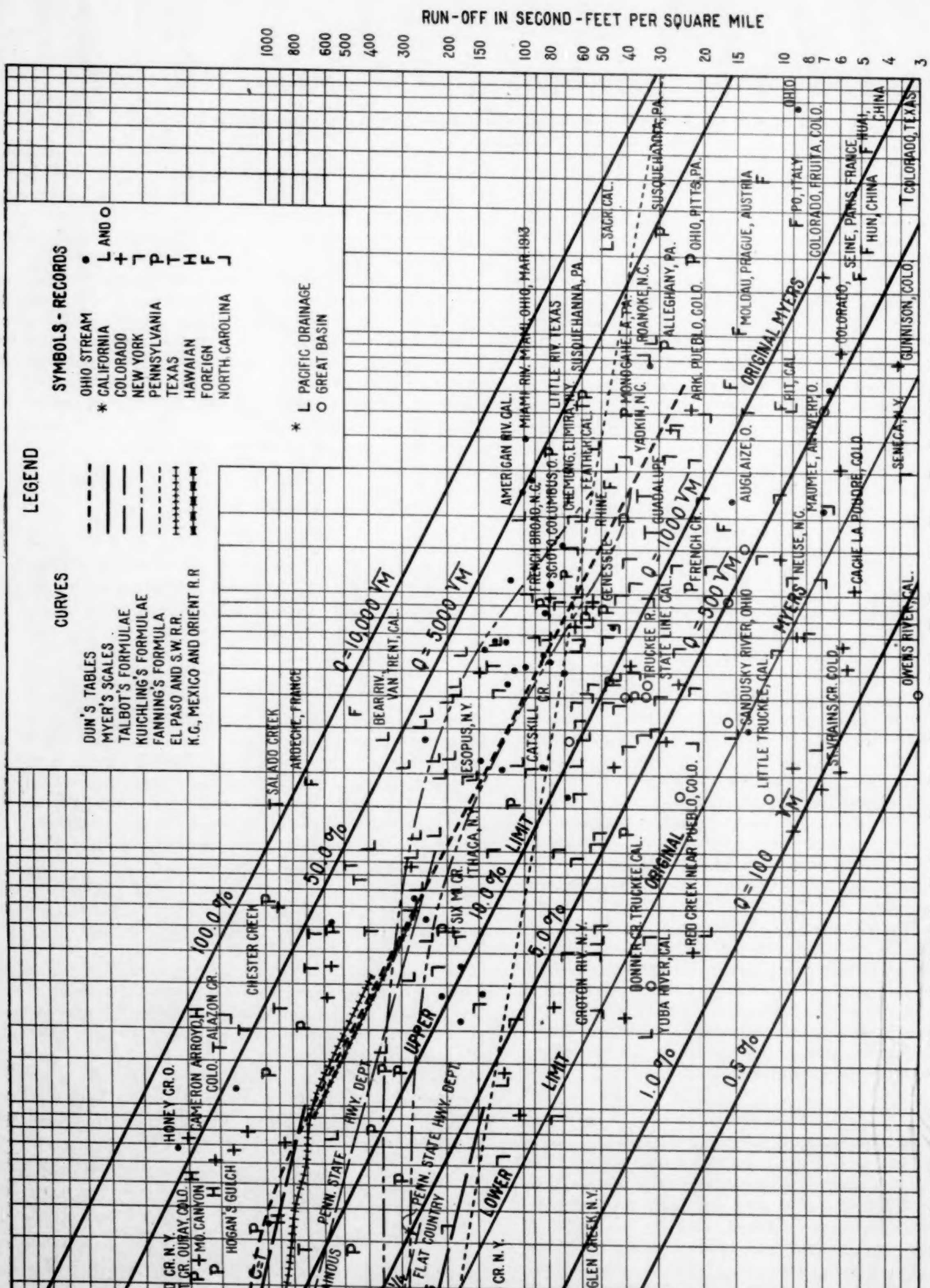

Fig. 1 —Graphic representation of selected run-off formulas, including the original and modified Myers formulas, and maximum run-off of representative streams

It will be observed from Figure 1 that the principal weakness of the most popular expressions for run-off is their limited scope, both geographically and numerically. It is typical of the best known formulas that C has no variation or a range of 4 or 6 at most, as in the original Myers and Talbot's, and it is apparent that such a range is not great enough to cover the field of the maximum flood flow data.

It will be observed, however, that the values of q as derived from the original Myers formula do bear a relation to the drainage area throughout the range from 1 to 100,000 square miles which more closely conforms to the mass of plotted data than the corresponding relation as determined by the other formulas, although it also is deficient in that the range of values of C is not great enough to include all the plotted points.

MODIFICATION OF THE MYERS FORMULA

Recognizing this fact it has been felt that a modification of the original Myers formula by increasing the range of the values of C might convert it into a form in which it would be suitable for adoption as a general run-off formula. A value of C equal to 40 being tentatively assumed as a maximum the resulting graph is found to lie above practically all the plotted points representing flood run-off rates and to conform closely to the enveloping curve, and the assumption of 40 as a maximum value for C is in this way justified. Substituting this value of C in the typical formula the resulting equation becomes:

$$Q=250\times40\sqrt{M}=10{,}000\sqrt{M}$$

Similarly for the lower limit, the locus of the point $q=\dfrac{100\sqrt{M}}{M}$, which corresponds to a value of C of 0.4, conforms well with the general slope of the band of platted run-off points, and lies practically at the lower limits of the band. These observed relations of the two assumed values of C to the field of the platted data suggest the idea that the modified Myers formula might be considered as

$$Q=R\sqrt{M}$$

in which R is the expected rate of run-off in second-feet from 1 square mile, varying between 100 and 10,000.

Moreover, the fact that the ratio of the maximum and minimum assumed values of C is as 100 to 1, and that these values just include the entire field of the platted run-off data, suggests the further possibility of comparing stream discharges according to the percentage, p, of the maximum for the corresponding area as obtained from the modified maximum formula, $Q=10{,}000\sqrt{M}$, which percentage is readily scaled in Figure 1 for any point platted. Adopting this idea, the final form of the revised formula becomes

$$Q=10{,}000\,p\sqrt{M}$$

and p becomes a percentage coefficient the value of which is to be determined for each particular watershed. As a variant form the equation may also be cast as $Q=100\,P\sqrt{M}$, in which P is the numerical value of the percentage rating.

This general formula is apparently applicable to all areas from 1 to 100,000 square miles or more. For areas less than 1 square mile it should be converted into the form, $Q=100\ P\ M$, otherwise discordant results will be obtained. This flattening of the slope of curves for small areas is characteristic of Murphy's, Kuichling's, Cramer's, Possenti's, and in fact all except the straight-line formulas. Dun's tabular values, also, show when platted that the yield is nearly proportional to the drainage area for all areas up to 3 square miles, but varies as the square root, approximately, for all greater values of M up to 6,500 square miles. (See fig. 1.)

Thus the modified Myers formula is mainly a transformation to the percentage basis and an extension of the original to cover the entire scope of ordinary practice. There may be other formulas just as capable of extension and modification to cover the entire field, but it will be difficult to find one more readily applicable, and agreeing with the platted run-offs more consistently. That such an extension of the scope is necessary is obvious from Figure 1. As well might we speak of a single unit strength for all materials of construction as to claim that a single value of a coefficient in any formula is applicable to the entire field of design. This fact was evidently recognized by Kuichling, Talbot, Dun, and Myers, for they each devised a range of values for C, thus defining a strip or zone as shown in Figure 1; but these zones are shown by the data recently collected to be much too narrow. Thus, the original Myers expression had a range of only from 2½ to 10 per cent as measured on the new percentage scale, and the other well-known formulas are similarly limited.

The superiority of the modified Myers scale in this respect and the necessity of a range as great as that suggested are illustrated by the wide range of the Ohio data platted in Figure 1. It is apparent that the Myers scale covers the field of design in Ohio more thoroughly and satisfactorily than any of the other formulas represented, yet the Ohio State highway bridge specifications approved June 10, 1925, for Federal-aid projects, prescribe the use of Talbot's, Kuichling's, and Fanning's expressions, none of which is adequate to cover all the Ohio run-offs represented in Figure 1.

MYERS FORMULA APPLICABLE TO WIDE RANGE OF AREAS

The most important claim made for the Myers formula is that it appears to express more accurately than the others the effect of the area of the watershed upon the rate of run-off. The variable coefficient C expresses the effect of various conditions of the drainage area with respect to vegetal cover, soil porosity, slope, storage, etc., but assuming these conditions to be approximately constant a single value of C may be used to determine the run-off from areas of widely different size.

From an exhaustive study of available hydrographic data there is considerable evidence of close similarity between the Myers scale ratings applicable to various sections of the same watershed or river valley and even between different rivers in the same general territory. Thus the Allegheny, Monongahela, and Ohio Rivers and many of their tributaries seem to have attained nearly 30 per cent, and marked departures from this rating are readily accounted for by abnormal conditions. Both the St. Lawrence and the Niagara, on the other hand, rate nearly 6 per cent as the result of storage in the Great Lakes; but it is a

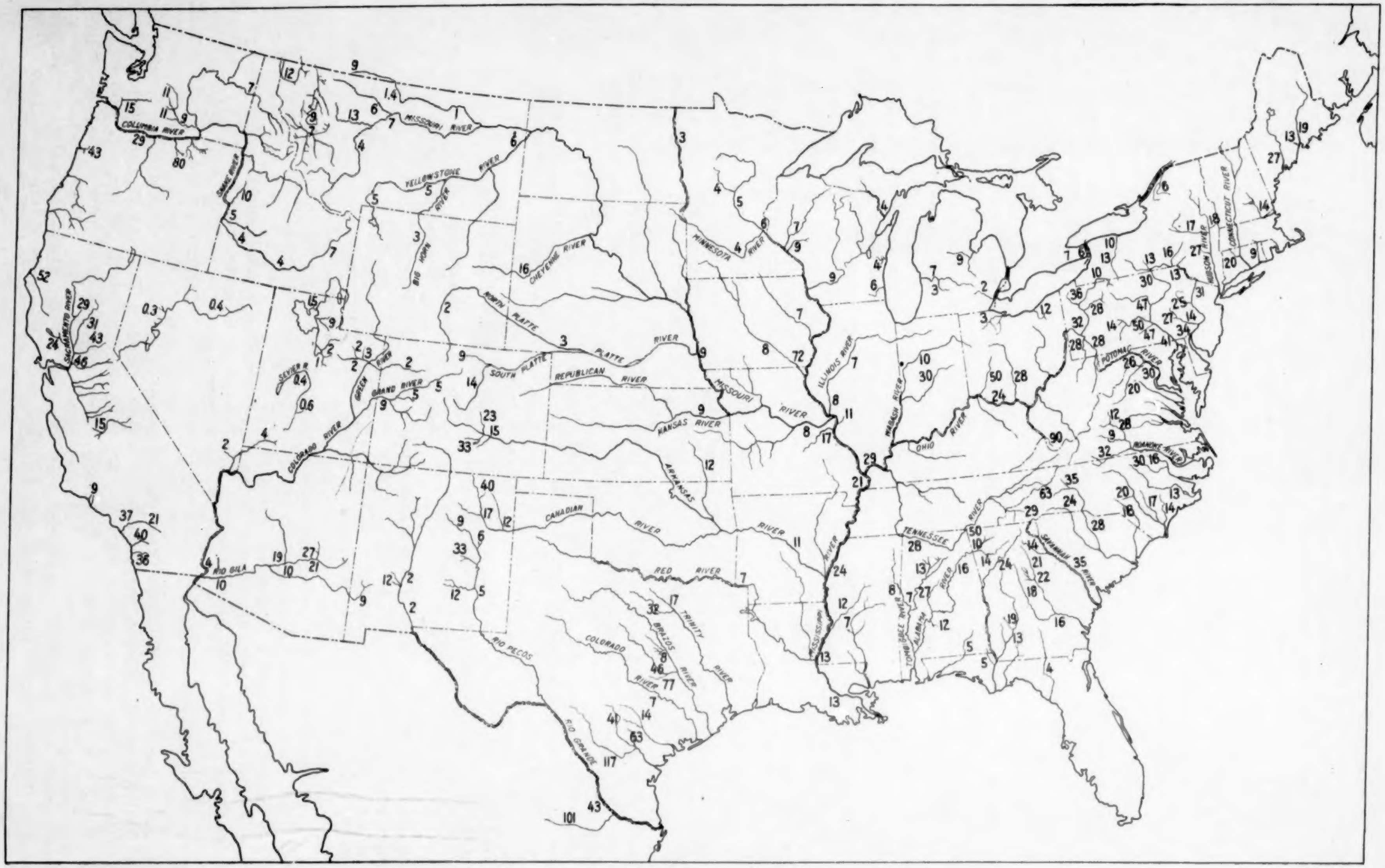

FIG. 2.—Myers scale ratings corresponding to maximum observed flood flows of streams in the United States

significant fact that their tributaries also range from 2 to 14 per cent generally, and average about the same intensity as the main rivers. The surface run-off is thus seen to be not more than a fourth of that which prevails in the Ohio drainage basin; yet within the two systems the ratings are relatively constant.

From numerous observations such as the above it appears that the Myers ratings as established for any given section of a drainage basin may often be applied to a more or less remote section of the same basin or even to a section of another but similar basin with considerable confidence in the approximate accuracy of the discharge as computed for areas of widely different magnitude. Percentages derived in this way must, of course, be regarded as first approximations only, subject to corrections representing changes in climatic, topographic or other physical characteristics which either detain or augment flood crests.

As a practical example of the possibilities in the use of the modified formula in this way there is the case of the Springerville bridge over the Little Colorado River in Arizona. A permanent masonry bridge had been designed which provided a waterway twice as great as that of the old structure. From all readily available data this would accommodate the highest stage of 50 years; and the designer therefore felt justified in adopting high embankments for approaches.

The representative of the Bureau of Public Roads who checked the proposed structure discovered that the waterway capacity would rate less than 3 per cent on the Myers scale, whereas several streams originating in the same mountains and somewhat similar with respect to the character of their watersheds, but of unequal drainage area, had been observed at from 10 to 21 per cent on the Myers scale. This prompted further investigation and it was established that the old bridge had accommodated only a minor portion of the maximum flood, for the adjoining meadows had functioned as a spillway too deep for fording. As a result the new bridge was given a larger waterway, and in addition one high approach embankment was eliminated and a by-pass substituted with capacity equal to that of the main structure. Thus at slight expense the flood channel was more than doubled, and the danger of impounding against a high earthen embankment and of sudden failure was removed.

Another instance that may be cited is that of the Rockville crossing of the Susquehanna a few miles north of Harrisburg. This crossing presented a complex problem, not only because of the high flood yields from this part of Pennsylvania, but because of the prolific and conflicting data according to the usual reckoning. It is well known that for small areas in this district Talbot's formula had to be expanded, by the use of a coefficient, C, equal to 2 or more in order to express the run-off rate; but that gave no direct information regarding the comparable flood volume from 24,030 square miles.

Expert analysis finally resulted in the adoption of a design providing a waterway corresponding to a value of C equal to 0.25 in Talbot's formula, or one-eighth of that which obtains for small areas. Records from distant stations could not contribute; they were unsatisfactory even as checks upon the computations for the bridge site in question, because they involved such dissimilar coefficients; therefore an independent solution was required.

ADAPTABILITY OF THE MYERS SCALE

Contrast that method with the one based on the Myers scale. According to this standard the ratings for typical areas on the headwaters, and also for such a major tributary as the Juniata at Newport seem to approach 50 per cent as a limit, and thus the presumption is that at least this intensity should be the basis of design for a permanent structure. Confirmation of this conclusion is afforded by the high record observed at Harrisburg in 1889, which attained 47.4 per cent.

It is important to note that a value of C equal to 0.25 in Talbot's formula corresponds to 40 per cent on the Myers scale for 24,030 square miles, so that the adopted basis of design is not far different from the one above derived. Furthermore, due weight should be accorded the influence of rapids at this crossing, thus warranting a higher velocity than 10 feet per second. A 50 per cent rating of waterway on the Myers scale with V equal to 10 is equivalent to a 40 per cent rating with V equal to 12.5 feet per second.

With a view to their usefulness in this way the Myers scale ratings corresponding to maximum observed flood flows of a large number of streams in the United States are presented in Figure 2. To anyone who appreciates the elements of detention and concentration as affecting run-off, the prevailing 9 per cent shown for the Missouri River is as appropriate as 50 per cent for the Miami, 24 to 32 per cent for the Ohio, and 0.4 per cent for the Humboldt River under desert conditions. Also, the ratings of 5 per cent around the Mississippi headwaters among glacial débris, 11 per cent at St. Louis, and 13 per cent in Louisiana are in line with what should be expected at the present stage of river control and land reclamation. The decrease of lateral storage by reason of new dyke inclosures will doubtless add to the severity of flood stages in the lower valley, and invite disaster if the Ohio River and other main tributaries reach maximum stages at the same time. This may not have occurred within the past century, but nevertheless it is properly included in the reckoning.

An abrupt change of percentage caused by the entrance of a tributary subject to violent floods may display the adaptability of the Myers scale as definitely as does the uniform rating of other streams throughout their courses. Thus, the Mississippi below Cairo rates 21 per cent, a compromise between the 11 per cent and 29 per cent attained by the main stream and tributary above the junction; but the Scioto, on the other hand, registers a uniform maximum of 26 per cent between the limits of 50 and 1,000 square miles of drainage area.

IDENTICAL PROBLEMS SOLVED BY VARIOUS FORMULAS

To illustrate the divergence of standard run-off expressions, and to test them all on the same basis, five identical problems representative of widely varying conditions have been solved and the results are recorded in Table 1. In general, it will be observed that each expression with the exception of the Myers formula serves satisfactorily for a restricted class of drainage areas, but fails to give consistent solutions for widely different conditions. The analyses by the Myers formula, on the contrary, yield results all of which are regarded as acceptable first approximations of the authoritative data, which were withheld from the writer until the analyses had been made.

Unpublished data collected by the division of agricultural engineering of the Bureau of Public Roads, provided the approved solutions for the Catoma, Marais des Cygnes, and Kootenai waterways; while for the Rockville crossing of the Susquehanna and the bridge over the Rio Grande at Brownsville, Tex., the high record floods observed during at least 30 years have governed. Reference to soil maps and a study of actual field conditions should furnish means for closer and more reliable estimates. The solutions recorded as obtained by the use of the Myers scale were dependent mainly upon the fragmentary information afforded by precipitation records, topographic maps, and the tabulations, illustrations, and discussions appearing in recent issues of the Proceedings of the American Society of Civil Engineers under the title of "Flood Flow Characteristics".[2]

A brief outline of the methods used would necessarily include reference to Table 2 of the above-named paper, which shows that the Verdigris River at Liberty, Kans., nearly 100 miles southerly from Ottawa, rated 9.1 per cent; the Neosho at Iola, midway between these two stations, rated 12.2 per cent; and the Kansas River at Lawrence, 30 miles northward from Ottawa, has been observed at 9.3 per cent. Comparison of topographic and precipitation data, together with fragmentary information as to surface conditions, hydrology, and vegetation, led to the conclusion that the extreme rating on the Marais des Cygnes at Ottawa would be 14.1 per cent, requiring provision for a flood flow of 49,880 second-feet. The highest flow of record was reported as 59,000 second-feet, of which nearly one-fourth was estimated discharge in the lateral channels.

[2] Issues Dec. 1924

METEOROLOGISTS' VIEWS OF THE MYERS SCALE

From preliminary studies it even seems probable that some relation exists between the percentage of rainfall which appears as run-off and the rating on the Myers scale. Expert meteorologists have indorsed this manner of expressing flood intensities, because it is consistent or even comparable with the factor of yield for a drainage basin.

For many watersheds the annual rainfall in inches multiplied by the average yield factor is numerically equal to the maximum rating on the Myers scale. It is recognized, of course, that this is purely an accidental relation. Thus central Florida with a mean yearly rainfall of 50 inches on porous soil, flat slopes, and dense vegetation yields about a tenth as run-off, and rates up to 5 per cent as shown in Figure 2. For southwestern Texas the corresponding figures are $15\times0.15=2.25$; for southern Ohio, $40\times0.75=30$; for northern Ohio, $35\times0.20=7$; for central Michigan, Wisconsin, and Minnesota, $30\times0.20=6$; for eastern Montana, $15\times0.40=6$; for north-central Nevada, $6\times0.10=0.6$; for the upper Sacramento Valley, Calif., $50\times0.55=27.5$; for northwestern Oregon, $90\times0.50=45$; for southeastern Pennsylvania, $45\times0.60=27$; for western North Carolina, $65\times0.60=39$; for eastern North Carolina, $48\times0.25=12$; and for eastern Maine, $40\times0.45=18$. For Pueblo, Colo., the maximum record attained during 1921 so far exceeded the 50-year mean of 11.56 inches as to merit adoption, and accordingly $20.28\times0.70=14.2$. All of the above would serve as first approximations to the percentages of rating on the Myer scale as recorded in Figure 2. Such methods of analysis should not, however, be allowed to take the place of thorough investigations, as special local conditions may alter the run-off intensities to a marked degree.

TABLE 1.—*Functions of the drainage area involved as a factor in each run-off formula, and typical solutions for waterway area derived therefrom*

Run-off formula	Area exponent		Waterway area required for run-off from 1 acre (0.0015 square mile)	Streams included in the test				
	Exact	Approximate		Catoma Creek, Ala.	Marais des Cygnes (Osage), Ottawa, Kans.	Kootenai, Bonner's Ferry, Idaho	Susquehanna, Rockville, Pa.	Rio Grande, Brownsville, Tex.
				Area of watershed in square miles				
				285	1,247	13,000	24,030	230,000
				Area of required waterway				
			Square feet	*Square feet*	*Square feet*	*Square feet*	*Square fete*	*Square feet*
Kuichling		−1	0.05 − 0.1	3,330-5,730	6,300- 10,700	10,800- 30,000	32,300- 52,500	207,000-505,000
Lauterberg	1		0.0002- 0.01	8 - 164	290- 500	2,130- 4,000	5,000- 10,000	100,000-200,000
Peck (former Mo. Pac. R. R. practice)	1		0.17 - 0.25	30,400-45,600	133,000-199,000	1,360,000 -2,040,000	2,563,000-3,845,000	24,500,000-36,800,000
Murphy		−1	0.024	2,630	5,600	24,100	40,700	350,000
Fanning	5/6		0.23	2,280	7,482	54,600	90,000	575,000
McMath	4/5		0.1 - 0.6	2,620- 9,000	10,000- 32,500	60,000- 208,000	100,000- 336,000	700,000- 2,050,000
Talbot and Burkli-Ziegler	3/4		0.16 - 1.0	1,450- 8,600	4,600- 27,500	26,000- 156,000	40,000- 240,000	215,000- 1,290,000
Fuller		0.8	0.1 - 3.7	2,200-10,500	6,500- 30,000	40,000- 190,000	65,000- 300,000	360,000- 1,700,000
Metcalf & Eddy	0.73		0.66	2,850	9,000	52,000	89,000	460,000
Chamier, Hawkesley, and Gray	3/4							
Tidewater Ry., Virginia	7/16		0.62	4,030	12,000	66,600	106,000	514,000
Churchill-Wentworth	1/3		1.0	3,200	8,660	40,800	61,600	273,000
Cooley	2/3							
Cramer		2/3						
Dun's tables	1-1/2		0.2 - 0.3	2,820- 4,580	5,670- 9,220			
O'Connell	1/2							
Dickens	1/2		0.9	376	786	2,540	3,450	10,700
Kutter		1/2	0.6	2,370	4,950	16,000	21,700	67,200
Hering, Dredge, Possenti		1/2						
Italian formulas		1/2						
Myers (original)	1/2		1- 4	425- 1,700	890- 3,560	2,900 - 11,500	3,900- 15,600	12,000- 48,300
Modified Myers	1-1/2		0.15- 15.0	170-17,000	356- 35,600	1,150- 115,000	1,560- 156,000	4,830- 483,000
Modified Myers with appropriate values of *P*	1-1/2		0.15 - 15.0	1,710	4,988	14,160	75,000	48,000
Authoritative solutions,[1] with $V=10$				1,440	5,900	12,600	65,000	38,000

[1] Not divulged until after analyses had been made with aid of modified Myers formula.

The Lauterberg formula, published in 1887[3] attempted to relate run-off to yearly rainfall. It may be written as $Q=0.082\ ChM$ where h is the total annual rainfall in inches and C varies from 0.2 to 0.7 for marshy and mountainous country respectively. The typical solutions shown in Table 1 illustrate the futility of that particular method of approach. Most of the formulas therein listed come within hailing distance of correct results in at least one column; but the absurd errors that attend other examples have left most of them in disrepute. The flexibility of the Myers scale and the soundness of the analysis based thereon have passed the preliminary tests, and justify further consideration. A similar claim can be made for the Talbot, Kuichling, Murphy, Dun, Kutter, Wentworth, and various other run-off expressions within the special and restricted fields for which they were devised.

ADVANTAGES OF THE MYERS SCALE

By adopting the two elements usually published by the United States Geological Survey and common to all run-off expressions, or easily derived therefrom, the Myers scale provides a means of comparison—a common denominator, so to speak—for all of the complex formulas in current use. Some of these take into account the assumed rainfall intensity, the slope, soil porosity, channel roughness, lateral storage, vegetation, axial directions of drainage and storm movements, time required for flow from the most remote parts, and the shape of the watershed. Outstanding is one similarity: They all seek either the required area of waterway or else the volume of flood discharge, and therefore take account of the run-off rate and the drainage area, the two coordinates of the Myers scale. Their conflicting methods of analysis and their limited scope have resulted in confusion and perplexities for investigators. For example, the Fanning formula for floods will rate 2 per cent on the Myers scale for 1 square mile, and 50 per cent for 16,000 square miles, while Talbot's formula with C equal to 0.2 rates 2.5 per cent and 28 per cent for the same areas respectively.

A study of the data presented in this article and the paper published in the Proceedings of the American Society of Civil Engineers, previously mentioned, warrants the following conclusions with respect to the advantages of the Myers formula as modified:

1. Run-off rates in California, Colorado, New York, North Carolina, Ohio, Pennsylvania, Texas, various foreign lands, and therefore all countries have been shown to be equally well represented on the Myers scale.
2. The use of various divergent formulas for any district will produce inconsistencies by neglecting certain portions of the desired field and overlapping others, as illustrated in Table 1.
3. The long recognized need for a general run-off formula to cover all conditions of practice may be met by the Myers scale.
4. Flood ratings on the Myers scale for any river section may provide a clue to run-off intensities elsewhere on the same watershed, irrespective of area. This is the most important claim set forth.

NEED FOR FIELD INVESTIGATIONS

As pointed out by the committee of the American Society of Civil Engineers investigating the failure of the South Fork Dam[4] there are other potential Johnstown floods that may be averted by prompt and intelligent action. Since that time both State and national supervision of such structures and channels have extended with obvious benefits to all concerned; yet there remains a field for important service by experts in a general reappraisal of the flood situation, guided by recent happenings and developments in analysis, forecasting, and design.

No doubt the proponents of each successive formula have been hopeful of its adoption for practical design purposes, yet the need for a general expression has not heretofore been satisfied. The Myers scale has withstood the preliminary trials, but the critical test of time and experience that comes only with time is yet to come; and its limitations are clearly recognized by all who have followed its development and application.

There has never been a more hopeful prospect for correlating and digesting the great mass of isolated hydrographic data than now lies before us, with interest widespread on account of recent flood disasters, with the special committee on flood protection data appointed by the American Society of Civil Engineers, and the governmental agencies well equipped and organized, and only awaiting financial support. A million dollars wisely spent now for such a purpose would furnish the best insurance against flood dangers to millions of citizens and billions of property values, and would warrant a corresponding decrease in annual premiums to underwriters.

[3] Proc. Inst. C. E. vol. 149, p. 392; quoted in 1911 Proc. Am. Ry. Engr. Assoc., vol. 12, pt. 3, p. 494.

[4] Trans. Am. Soc. Civ. Engrs., vol. XXIV, June, 1891, p. 431.

URBAN ASPECTS OF HIGHWAY FINANCE[1]

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The first section of this paper, dealing with the special interests of cities and urban motor-vehicle owners in the highway finance policies and practices of State and county governments was published in the January issue. The remaining sections dealing with the methods and problems of urban highway finance and with certain financial aspects of the traffic-congestion problem are combined in this article.

THE most formidable difficulty which research in the problems of highway finance encounters is the lack of adequate statistical data, and this lack is even greater for urban than for rural highway finance. Such data as are available are rarely sufficiently detailed or suitably classified to serve effectively the purposes of research in the problems of urban highway finance, and it is, for instance, impossible to determine with any close degree of accuracy the amounts of urban highway expenditures and the sources of urban highway revenues for the larger American cities.

URBAN HIGHWAY EXPENDITURES

Table 1 presents the statistics of highway expenditures in 1923 of all American cities over 30,000 in population, as compiled by the Federal Census Bureau. To obtain all-inclusive figures, it would be necessary to add to the total of $324,607,000 shown in the table a substantial item for interest on highway indebtedness, another substantial item for the portion of police department expenditures incurred in connection with traffic regulation, and a minor item for the costs of pavement construction and maintenance, snow removal, and street sprinkling incurred by electric railways in carrying out their franchise obligations. There are no data upon which to base even rough estimates of the amounts involved in these additional items, but it seems to the writer a reasonable guess that if these were added the total highway expenditures would not fall short of $400,000,000 per annum. If there be added the expenditures of the thousands of incorporated places under 30,000 in population, the total figure might well reach $450,000,000, or about 45 per cent of the total expenditures on rural highways.

TABLE 1.—*Highway expenditures of American cities over 30,000 in population, 1923* [1]

	Expenditures	Total
OUTLAYS		
Streets, roads, and alleys	$177,010,000	
Other highway structures	23,722,000	
All other	3,911,000	
		$204,643,000
EXPENSES		
Supervising departments	2,388,000	
Roadways	52,069,000	
Other highway structures	11,603,000	
Prevention of street dust	3,189,000	
Snow and ice removal	8,277,000	
Street lighting	34,967,000	
Waterways	902,000	
Repair and construction for compensation	6,569	
		119,964,000
		324,607,000

[1] U. S. Bureau of the Census, Financial Statistics of Cities, 1923.

CITY STREET EXPENDITURES NOT INCREASED BY MOTOR VEHICLES

Table 2 presents data illustrating the trend of per capita highway expenditures for 146 cities for which continuous comparable data were procurable. If these cities can be taken as representative of the general urban situation, per capita urban expenditures for highways have increased only moderately in the last 20 years, and if allowance is made for the decline in the purchasing power of the dollar they have decreased. Such increase as is shown in the table has been confined to the postwar period, and much of it could reasonably be explained as due to high prices and to an attempt to make up for the enforced curtailment even of urgent expenditures during the period of the war, without reference to other causes. The cities have been increasing their expenditures on other services much more rapidly than on highways. This is in sharp contrast to the situation with respect to rural highways, for there has been since the advent of the automobile a very marked increase, both absolute and in relation to State and county expenditures on other activities, in the per capita expenditures on rural highways. A rough estimate shows, for example, that the per capita expenditures of the American people on rural highways were about $2 in 1910, $5 in 1920, and $8.50 in 1923. This contrast would appear to indicate that the development of motor transportation has exercised a much less marked influence on urban than on rural highway expenditures.

TABLE 2.—*Per capita expenditures for highway purposes of 146 American cities, 1903 to 1923* [1]

Year	Outlays	Expenses	Total	Percentage of total expenditures for all purposes
1903	$3.62	$1.64	$5.26	27.7
1905	2.87	1.67	4.54	22.4
1907	3.26	1.91	5.17	22.5
1909	3.29	1.71	5.00	21.4
1911	3.79	2.04	5.83	22.9
1913	3.39	1.93	5.32	21.4
1915	3.76	2.06	5.82	21.7
1917	3.25	1.96	5.21	20.1
1919	2.41	2.04	4.45	16.3
1922	4.85	2.87	7.72	16.8
1923	5.22	3.01	8.23	17.3

[1] Computed from data in U. S. Bureau of Census, report on Financial Statistics of Cities, 1923.

The cities have been growing rapidly in population, and therefore in density of population per square mile. On the supposition that an explanation of the moderate increase in recent years in the per capita highway expenditures of cities might be found in the increasing density of urban population, Table 3 was constructed to test the hypothesis. If the increase in density of population, other things remaining the same, tends to reduce the per capita highway costs, the per capita expenditures for highways should vary, as between cities of different population, inversely to population. Table 3, however, indicates that there is no significant difference in the highway expenditures per capita between cities grouped according to size of population, and fails, therefore, to confirm the hypothesis. An examination of the detailed data for individual cities likewise fails to reveal any tendency of per capita highway expenditures to vary inversely to the size of the city.

[1] Part of a report presented by the writer before the annual meeting of the Highway Research Board National Research Council, at Washington, D. C., Dec. 3, 1925.

Table 3.—*Per capita highway expenditures of cities classified according to population, 1923*

[Computed from data in U. S. Bureau of the Census, report on Financial Statistics of Cities, 1923]

Population	Outlays	Expenses	Total
500,000 and over	$4.77	$3.37	$8.14
300,000 to 500,000	6.31	3.32	9.63
100,000 to 300,000	5.19	2.80	7.99
50,000 to 100,000	5.70	2.50	8.20
30,000 to 50,000	5.51	2.80	8.31

The failure of the urban statistics to disclose any such marked influence on urban highway expenditures of the growth of motor transportation as is apparent in the statistics of rural highway expenditures is perhaps to be explained by the following factors, which are presented as tentative hypotheses and not as observed facts:

1. The development of motor transportation has increased traffic on rural highways relatively more than on city streets and has therefore made necessary relatively greater increases in expenditures on rural than on urban highways.

2. The city street systems, at least in so far as width, mileage, and substructures were concerned, and possibly also with respect to type of surface, were better prepared to meet the demands of motor transportation than were the rural highways prior to the modern era of highway improvement.

3. On city streets the adjustment to the increased volume of traffic has been made in large degree by permitting congestion to develop and by restrictive legislation, whereas on rural highways, extension of facilities was more flexible, because it was not seriously hampered by high cost of the additional land necessary for such extension nor by the location thereon of expensive buildings, and adjustment has consequently been effected in greater degree by providing increased facilities for traffic.

SOURCES OF MUNICIPAL HIGHWAY REVENUES

American municipal expenditures for highway purposes are in the main financed out of the general revenues of the cities, and even where special funds exist for highway purposes the published statistical returns often fail to segregate them. It is impossible, therefore, to ascertain even approximately for the cities as a whole the specific sources from which their highway revenues are derived, and the amounts and proportions from each source. There is available, however, some material which if analyzed indicates in a general way the sources of municipal highway revenues.

Special motor vehicle taxes.—There are no compilations of the amounts of revenue derived by American municipalities from either special municipal motor vehicle taxes or from grants or refunds from State motor vehicle taxes. The census report on Financial Statistics of Cities for 1923 shows, however, that the receipts in that year of all American cities over 30,000 in population from "general licenses" amounted to $12,417,001, and a comparison of the detailed figures given under this head with evidence from State and city financial returns indicates that revenues from motor vehicle license taxes comprise at least 90 per cent of this amount, and that the figure given includes the share of cities in the receipts from State motor vehicle license taxes as well as the revenues from the few municipal motor vehicle taxes, which are independent of, or additional to, the State taxes.

An analysis of the detailed data from this and other sources leads to the estimates that in 1923 American cities over 30,000 in population shared in the receipts from State motor vehicle license taxes to a total amount of not less than $7,000,000 and not more than $8,000,000, and that these cities received from separate municipal motor vehicle taxes not less than $4,000,000 and not more than $4,500,000. Only seven cities over 100,000 in population imposed municipal motor vehicle license taxes, namely, Chicago, St. Louis, Kansas City, Louisville, Omaha, Richmond, and Memphis, and these seven cities collected approximately $4,000,000, of which approximately three-fourths was collected by Chicago alone. To these amounts should be added shares of the cities in State gasoline taxes and also receipts from special municipal taxes on both public and private vehicles, for which no data are available. It is assumed that $10,000,000 is a generous estimate to cover these additional items for the year 1923.

Receipts from highway privileges.—The Census Bureau reports for 1923 receipts from highway privileges for all cities over 30,000 in population totaling $26,700,000. These cover payments from steam and electric railroads (also from bus and taxi companies for the privilege of using the streets) and receipts from public utilities for the privilege of placing wires, pipes, poles, and other equipment on or under the streets, charges for the privilege of maintaining vaults under sidewalks, etc.

Receipts from earnings of highway departments.—The Census Bureau reports for 1923 receipts from earnings of highway departments of all cities over 30,000 in population a total of $7,955,684, of which $7,211,235 covered receipts in compensation for repair and construction, not explained but probably referring to pavement repairs and construction required or made necessary by and compensated by electric railways and by public utilities locating their equipment in the subsurface.

Receipts from subventions and grants by other civil divisions.—The Census Bureau does not separate receipts of cities from subventions and grants by other civil divisions for highway purposes from receipts for other purposes but the total receipts in 1923 of all American cities over 30,000 in population from State and county subventions and grants for other purposes than education amounted to $10,294.276. It is probable that the great part of these grants was for highway purposes, and it will be estimated that highway grants amounted to $10,000,000.

Receipts from special assessments and special charges for outlays.—The Census Bureau does not separately classify the purposes for which special assessments are levied. In 1923 the total receipts, of all cities over 30,000 in population, from special assessments were $122,273,060, of which $117,966,561 were for capital outlays and $4,306,505 for current expenses. Some of these receipts were from assessments for sewers, parks, and other nonhighway purposes, but the predominant use of special assessments by American cities is to provide funds for highway purposes, and it is a conservative estimate that of these receipts $100,000,000 were for such purposes.

TABLE 4.—*Estimates of highway revenues of American cities over 30,000 in population by sources compared with highway expenditures, 1923*

	Revenues	Percentage of total expenditures
HIGHWAY EXPENDITURES		
Outlays	$204,643,000	
Expenses	119,964,000	
Total	324,607,000	
HIGHWAY REVENUES		
Apportionment of receipts of State motor vehicle license taxes	[1] 7,500,000	[1] 2.3
Municipal motor vehicle taxes	[1] 4,250,000	[1] 1.3
Apportionment of receipts of State gasoline taxes, and municipal taxes on bus and truck lines and vehicles for hire	[1] 5,000,000	[1] 1.5
Receipts from highway privileges	26,700,000	8.2
Receipts from earnings of highway departments	7,955,000	2.5
Receipts from State and county grants	[1] 10,000,000	[1] 3.1
Receipts from special assessments and special charges for outlays	[1] 100,000,000	[1] 30.8
Other sources	[1] 163,202,000	[1] 50.3
Total	324,607,000	100.0

[1] Estimated.

In Table 4 the estimates of highway revenues by sources are tabulated and compared with the total highway expenditures of cities. It should be remembered that the statistics of highway expenditures do not include the interest payments on highway indebtedness, the expenditures of police departments on traffic regulation, nor the costs to electric railways of the paving and other highway services which they are required to contribute. On the other hand, the total figures for highway revenues do not include the value of the highway services rendered by electric railways. The amount attributed to "other sources" must come in the main from property taxes or from receipts from bond issues, and the bond issues will in the main eventually be liquidated from the receipts of property taxation. In 1923 over 92 per cent of the tax receipts of American cities over 30,000 in population was derived from property taxes. If this percentage be applied to the figure in Table 4 for "other sources" and if it be assumed that all State and county grants to cities for highway purposes are derived ultimately from motor vehicle taxation, the estimate is reached that the highway expenditures for 1923 of American cities over 30,000 in population were, or would eventually be, financed: 45.3 per cent from taxes on property; 30.8 per cent from special assessments on property; 10.7 per cent from highway earnings; 8.2 per cent from motor vehicle tax revenues; and 5 per cent from other sources. If the estimate that the inclusion of omitted items would raise the total to $450,000,000 be accepted, the percentages would be about as follows: Property taxes, 59 per cent; special assessments, 22.2 per cent; motor vehicle taxes, 5.9 per cent; highway earnings, 7.7 per cent; other sources, 5.2 per cent.

MOTOR TRAFFIC AND URBAN HIGHWAY FINANCE

This situation contrasts sharply with the method of financing rural highways, especially because of the small percentage of urban highway revenue which comes from motor vehicle taxation as compared to the 50 per cent or so of the rural highway revenues which are derived, either in actual fact or in equivalence, from Federal and State taxes on motor vehicles and gasoline. Are there any valid reasons why motor vehicles should contribute in so much smaller proportion to the cost of city streets than to the cost of rural highways?

In the first case, the use of rural highways for other purposes than motor transportation is now negligible, whereas city streets are used to an important extent by pedestrian traffic, electric railways, and in some cities horse-drawn vehicles. If the principle of charging the costs of highways to users were rigidly followed, all of the sidewalk costs and a substantial cost of the crossings at intersections should be charged to pedestrian traffic. The city itself should also bear a part of the costs proportionate to the use of city streets by municipal fire, garbage disposal, police, and other service vehicles. The electric railways and horse-drawn traffic should also contribute.

Second, rural highways serve no other purpose than transportation wh reas city streets serve a variety of other purposes. They are the means of access of light and air to the adjoining buildings. They serve as fire barriers between city blocks. Their surface and underground areas are used as the locations for the equipment of most public utilities, telegraph and telephone poles and wires, water, sewage, and drainage mains, gas mains, and electric wires, etc. Where they are parked or boulevarded, or where trees and lawns are maintained within the street area, the streets serve as elements in the beautification of the city and as recreation areas for the city population.

Third, most of the highway services such as street lighting, abatement of dust, removal of snow, street cleaning are not made necessary solely by the existence of vehicle traffic, and serve, not only such traffic but also pedestrian traffic and the occupants of adjoining buildings. Rural highway services to other than vehicular traffic are negligible, and under some cicumstances rural highways are a detriment rather than an advantage to immediately adjoining property.

ITEMS OF STREET COSTS CHARGEABLE TO MOTOR VEHICLES

It has already been shown that the per capita highway expenditures of the cities have not increased greatly since the advent of the automobile, and that if allowance be made for the decline in the purchasing power of the dollar they have actually decreased. It is undoubtedly true, however, that the per capita expenditures, such as they are, are greater than they would be if there had not been so tremendous a development of motor transportation. The principle supported by the highway finance committee of the National Tax Association that the costs of rural highways should be borne by the users thereof is applicable to urban highways in the same way and for the same reasons *to the extent that the fundamental conditions are similar*. The costs of providing urban facilities for motor transportation, to the extent that these facilities are made necessary by the growth of motor transportation and serve no other important purpose than that of facilitating such transportation, should be met by charges on the users of such transportation.[2] What proportion of the total urban highway expenditures is properly to be charged to motor vehicles it is impossible to estimate with any reasonable degree of accuracy until more detailed statistics of the objects of such expenditures are made available and until those in charge of the operation of the various urban highway services analyze these operations with a view to ascertaining the relative degrees in which various urban activities benefit therefrom.

[2] Subject, however, to the qualification made later with respect to special assessments.

The items in the urban highway costs which can with most certainty be charged to motor vehicles are the costs of construction and maintenance of roadway pavements, of street widenings made necessary by the growth of motor traffic and of traffic regulation. It seems doubtful that motor traffic has a sufficient degree of responsibility for any of the other items in the highway bill to justify imposing upon it the cost thereof. Even for the items here specified, certain important deductions should in equity be made. Other types of transportation using the paved surfaces should share the costs with motor traffic in proportion to use thereof and damage thereto. The city should meet out of its general tax revenues a portion of these costs to cover the pedestrians' share therein. There should not be charged to motor traffic any repair or other pavement costs made necessary by operations in connection with the subsurface utilities. The city should also meet out of general or departmental funds a share of these costs proportional to the use of the roadways by its own vehicles. Motor traffic should be credited, toward its share of these costs, with whatever revenues the city may receive from State or county which are derived from motor vehicle taxation.

SPECIAL ASSESSMENTS IN URBAN HIGHWAY FINANCE

The estimate was made above that special assessments levied against land assumed to benefit from highway improvements and levied in proportion to the assumed benefits, in 1923, met half the cost of "outlays" or capital expenditures for durable highway improvements. The "benefits" to land from highway improvements are ordinarily not benefits separate and distinct from the direct benefits of the improvements to the users thereof, but are a different manifestation of the same benefits. The benefit to land from a highway improvement is for the most part merely the result of the ability of the landowner to extract from the user of the improvement all or part of the monetary value of the improvement to the latter. Land adjoining a new highway improvement rises in value precisely because it is anticipated that its owner will be able to perform such an extraction, and it rises in the measure of such anticipation. To the extent that there is a benefit to land, there is, with minor qualifications, an equivalent subtraction from the net benefit to the user of the improvement.

If a highway improvement is financed by special assessments against actual increases in land values unmistakably resulting from the improvement, this makes certain that the cost of the improvement shall be paid out of that portion of the benefit to the users of the improvement which the landowners expect to be able to appropriate for themselves, but in the absence of friction and assuming the accurate assessment of costs against benefits to adjoining land, it is theoretically possible that charges against users and assessments against benefited land, whichever method is adopted, shall in the final incidence be borne fully by the owners of the benefited land.[3]

Assuming the possibility of the satisfactory administration of special assessments, they are generally preferable to taxes on highway users, because they reach the benefits where they concentrate in relatively few hands and where the entire spread of the benefits over the duration of the improvement is at once capitalized and thus made available for immediate assessment. Where a highway improvement of a durable sort results beyond reasonable doubt in a substantial increase in the market value of neighboring land, it is clearly more equitable to charge the cost of the improvement against the benefited land, but with the amount of the benefit to the land as a maximum for the assessment, rather than to spread the cost through general property taxation on property of all kinds and locations, regardless of its share in the benefits resulting from the improvement. To most persons also it would seem more equitable to charge the costs against the benefits to land rather than against such benefits as the landowners permit to remain with the users.

SPECIAL ASSESSMENTS MORE APPROPRIATE FOR URBAN THAN RURAL HIGHWAY FINANCE

There is much greater scope in urban than in rural highway finance for the use of special assessments as a substitute for taxes on highway users to meet the costs of durable highway improvements. Special assessments can not be properly administered unless there result from the improvements which they are intended to finance substantial, concentrated, and readily ascertainable increases in the value of land in the immediate neighborhood of the improvement. This is much more likely to be the case for street improvements than for improvements to rural highways. The chief benefit to land values from a new rural highway may be in the urban centers at its extreme limits, or the benefits may be spread lightly over a wide area extending across county and even State lines. In rural highway finance the only effective way of reaching the important beneficiaries of improvements is to tax the immediate beneficiary—the highway user. In urban highway finance, special assessments may often be a more certain and more convenient method of achieving this purpose.

There is need of caution, nevertheless, in the use of special assessments. It is generally taken for granted that because ordinarily they are subject to the legal principle that the assessment must not exceed the value of the benefit and because their administration is always subject to certain legal restrictions intended to safeguard the assessee, special assessments are always in fact, what they must be in law, special charges against special benefits. There is reason to believe that in most cities where special assessments are much used, there is inadequate technique for ascertaining the existence, the location, and the amount of benefit, and the special assessment tends to become merely a special land tax levied over an arbitrarily delimited area and with erratic variations of rates as between different parcels of land. Very often what appears to be an increase in land value due to an improvement may upon examination turn out to be merely part of a general rise in land values and often a fictitious one due to the decline in the purchasing power of the monetary unit.

Very often the anticipations of landowners with respect to the stimulus which a projected improvement will give to land values transpire after the event to have been mistaken. Many improvements are competitive in their effect on land values. An improvement in locality *X* gives it an advantage over locality *Y*

[3] This assumes that the users of the improvement are "ultimate consumers" of the service it renders, for example, travelers for pleasure, and do not pass the benefit on to employers of their services or to purchasers of their products, as well as to adjoining landowners. For other than pleasure traffic, charges on users are theoretically preferable to special assessments, because they will be passed on in part at least to all the ultimate beneficiaries of the improvement and not to one class of beneficiaries, landowners, alone.

which shows itself in a rise in land values in X. Locality Y thereupon undertakes a similar improvement and its land values again come to a parity with values in X. But X has now lost its temporary superiority and its land values fall back to their original level. The result of an investigation covering a number of years would under such circumstances show little or no effect on land values in X and Y of the improvements made by them, but the usual technique of special assessment, which deals only with prospective benefits of an improvement not yet made and disregards the effects of the improvement on land values outside the area of supposed benefit, would here find a proper basis for the levy of benefit assessments. All persons with special-assessment experience know of instances where improvements financed by special assessments have lowered the market value of the assessed land because of the assessment burden for which it was made liable. It has been only the general rise in land values, due to growth of population and to the general rise of prices, which has kept the shortcomings of the special assessment as commonly administered from receiving the serious attention which they call for.

TAXATION OF ELECTRIC RAILWAYS FOR HIGHWAY USE

It is the common practice in American cities to levy a privilege tax on electric railways for the privilege of using the city streets, or to require them to construct and maintain at their own expense the paving within the track space and for a specified distance on each side. They are also required in some cities to remove the snow and to sprinkle the streets on which they operate. The item "receipts from highway privileges," amounting in 1923 to $26,700,000, includes amounts received from electric light, telephone, and water companies for the privilege of using the surface or subsurface of streets for their structures and equipment, and also receipts for the privilege of maintaining vaults under the streets; fruit, gasoline, and other stands on the streets; and awnings, signs, etc., extending over the sidewalk. But a large portion of these receipts consists of amounts paid by electric railways for the privilege of using the streets.

In 1919, after which year the Census Bureau returns ceased to differentiate between the various types of highway privileges, the revenue from charges for the use of space on or under the highways by privately owned public utilities, mainly electric railways, amounted to 93 per cent of the total receipts from highway privileges, as compared to 7 per cent from charges for the use of space for miscellaneous special purposes, such as awnings, gasoline pumps, signs, etc. It has been estimated, also, that the annual cost to American electric railways of rendering the paving services required by their franchises exceeds $20,000,000. This probably includes the item amounting to $7,211,000 for 1923 of compensation to city highway departments for repair and construction services, most of which undoubtedly came from electric railway companies which, instead of doing their own paving, had it done for them at their expense by the municipal highway departments. In a few cases, as for instance Chicago, the city also receives a share of the receipts of the surface railroads.

The electric railways make, therefore, a substantial annual contribution to the cost of urban highways. Their representatives, in fact, complain that they make too large a contribution, especially as compared to motor transportation, and that this discrimination in taxation operates as a subsidy to competing methods of urban transportation. They protest especially vigorously against the paving requirements, which they characterize as an obsolete survival from the days of horse cars, when the horses did actually wear out the pavements.

There is no evident reason why electric railways should contribute more heavily in proportion to their use of city streets than other types of transportation, and it is in fact desirable that competing types of transportation should bear the highway costs properly attributable to them in proportion to their use of the highways, in order that their relative capacity to render transportation service should be tested under equal conditions. The fact that electric railways are common carriers, whereas private automobiles are not, should have no bearing on the question, since the special privileges enjoyed by a common carrier are granted in the public interest rather than in the interest of the carrier and are accompanied by special and onerous obligations and restrictions. But if electric railways are being required to make too great a contribution to highway revenues, it is only true, if true at all, in comparison with other types of transportation. In so far as the paving and snow removal requirements are concerned, they are clearly arbitrary and have no necessary relationship to the costs to the cities resulting from the operations of electric railways. Under existing conditions, electric railways should be required to meet the highway costs incurred by the cities on their behalf to the same degree as such requirement is imposed on other types of vehicular traffic using city streets.

In so far as paving is concerned, it is proper to attribute to electric railways such increase in the costs of construction and maintenance of pavement as result from the presence of tracks and the operation thereon of street cars. How this increase can be computed is a problem for the engineers, but the type of test suggested by some engineers, namely, a comparison of the paving costs on two streets of similar width, one with and one without street-car tracks, is clearly defective unless the character and volume of vehicular traffic on both streets is constant and unless the same standard of maintenance is applied to both streets. But in large cities, and especially in the congested portions thereof, space utilization is a more important economic factor than the wear on pavements, and a thoroughgoing apportionment of highway costs would take into account the comparative utilization of space of the different types of carriers as well as their wear on the pavements.

FINANCIAL ASPECTS OF URBAN TRAFFIC CONGESTION

A careful survey of the American literature on the traffic congestion problem has made it clear to the writer that the explanation of the causes of traffic congestion and the appraisal of the comparative merits of the many proposals which have been made for its solution are primarily technical problems for the engineer and the transportation expert to deal with. There are, nevertheless, some angles, of the problem which are at the same time important and of special concern to municipal finance, and with these I propose to deal briefly.

Any program of highway improvements to remedy traffic congestion raises four fundamental financial questions:

1. How much will it cost?

2. Is there any alternative program which would bring greater relief at the same cost, or the same degree of relief at less cost?

3. Is the relief it will bring of sufficient economic importance to warrant its cost?

4. Who should pay the cost, and how?

Estimating the costs of public improvements and the results of such improvements on traffic conditions is of course a technical task which belongs presumably to the highway and traffic engineers. The question: Who should pay the costs and how, has already been dealt with at some length. It may be added, however, that whether the municipal government meets the costs in the first instance by taxation or by borrowing, the long-run costs to the community as a whole will in either case be the same. For the policy of financing an expensive program of highway improvements by borrowing it can be argued that it is not as likely as the pay-as-you-go method to lead to the costly and uneconomic postponement of the making of improvements until long after the need for them has become urgent. The voting public is almost everywehere more favorably disposed toward projects for highway or other major public improvements if they are to be financed by borrowing instead of by current taxation. On the other hand, it can be argued for the pay-as-you-go policy that it is less likely to lead to a premature or overambitious program of expenditures. Ordinarily, however, if the improvement program is extensive and can not conveniently be carried out in gradual stages over a period of some duration, it can not in practice be financed out of current taxes and must be either financed by borrowing or abandoned. The arbitrary debt limits to which many cities are subject often operate as insurmountable obstacles to the execution of urgent programs of highway improvement. There remains the most fundamental and the most difficult question of all, namely, is the project worth its cost?

WHAT IS MEANT BY TRAFFIC CONGESTION

The first requisite for an adequate analysis of the problem of traffic congestion would appear to be a careful definition of "congestion." The nearest approach to a formal definition which I have been able to find in the literature is the following: "The meaning of the term 'congestion' as applied to traffic conditions in this report is that degree of overcrowding of vehicles in streets that obstruct freedom of circulation, with attendant consequences of economic waste, and inconvenience." But maximum freedom of circulation, convenience and economy for an individual vehicle is to be obtained only if there are no other vehicles on the road. This is defining congestion by calling it overcrowding, which is not very helpful. There are two different senses in which the term is commonly used: (1) To indicate such a volume of traffic on the roads as to reduce below its potential maximum the speed at which traffic moves, and which I will call "retardation of traffic," and (2) To indicate the presence on the roads of so great a number of vehicles as to reduce the "traffic capacity" of the roads, whose consequences I will term "supppression of traffic."

The term "traffic capacity" of a street is used to indicate the number of vehicles per hour which can be passed through at a given point in the street. The traffic capacity of a street increases sharply with increases in the speed of movement of traffic until a speed of about 14 or 15 miles per hour is reached. At speeds higher than this the traffic capacity of the street steadily decreases with increases in the speed of movement because of the increase in the safe braking space between vehicles. For an uninterrupted stream of traffic, the theoretical traffic capacity at a speed of traffic movement of 14 or 15 miles per hour appears to be about 125 per cent of the capacity at 30 miles and about 140 per cent of the capacity at 40 miles. Below 15 miles per hour, speeding up of traffic therefore increases traffic capacity, above 15 miles per hour it decreases traffic capacity.[4]

Traffic congestion therefore has two phases: (1) The retardation of traffic, and (2) the suppression of traffic. An increase in the number of vehicles on the road always tends to retard the rate of movement of the traffic. If the increase in the number of vehicles goes beyond a certain point it not only retards traffic but it reduces the amount of traffic which can be passed through the street per hour. Where the only speed restriction is that which is the automatic result of the number of vehicles on the road, reduction of speed retards traffic until a minimum of speed of about 14 miles per hour is reached, but increases traffic capacity; further reduction of speed not only retards traffic but it also suppresses traffic by reducing traffic capacity.

There are to be found scattered through the literature on the traffic problem numerous estimates of the economic loss to different urban communities resulting from the prevailing traffic congestion. Recently an estimate of $2,000,000,000 per year for the United States as a whole due to traffic congestion and improper control of traffic facilities has been given wide publicity. These estimates of the costs of traffic congestion commonly ignore the "suppression of traffic" phase of traffic congestion, although they deal almost exclusively with traffic areas where congestion has retarded the rate of traffic movement to far below the rate of maximum traffic capacity and has therefore resulted in considerable suppression of traffic. Though they profess to be estimates, therefore, of economic costs of retardation of existing traffic, in no case that I have encountered is any indication given of the basic speed, 10 miles per hour, 30 miles per hour, 60 miles per hour, or whatever it may be, from which the degree of retardation, and by inference the amount of time and money lost, are measured. Acceptance of the current estimates as reasonably accurate would be much easier if it were made clear just what it is that they estimate. In any case, estimates of the costs of congestion should take into account the economic loss due to suppression of traffic, which, for all we know, may be more important than retardation of traffic. The development of a satisfactory technique for estimating the costs of traffic congestion will not come until congestion is analyzed and dealt with in quantitative rather than qualitative terms.

REMEDIES FOR TRAFFIC CONGESTION

Any program for the relief of traffic congestion should be written in terms of the volume and character of traffic for which provision is intended to be made and the standard of provision which it is planned to give to it. Provision should be made, of course, for anticipated expansion of traffic, estimated as best it

[4] Cf. Regional Plan of New York and Its Environs, Highway Traffic in New York and its Environs, Lewis and Goodrich, pp. 80 ff.

can be from such factors as population trends, automobile registration trends, per capita passenger mileage movements per annum as density of urban population increases, etc. Estimates of prospective needs for traffic facilities are often so made as to imply that all that is sought for the future is the avoidance, as the volume of traffic grows, of any intensification of the existing degree of congestion. Most such estimates, moreover, overlook the stimulus to traffic which results from the extension of traffic facilities of itself, and which would lead to an increase in traffic after the extension was made even though pouplation, motor vehicle registrations, and other such basic factors remain constant.

The methods proposed by traffic engineers for the relief of traffic congestion fall into five classes: (1) Improved traffic guidance, (2) minor improvements to existing traffic facilities, (3) major extensions of highway facilities, (4) zoning and decentralization of business, (5) traffic restriction. Any expense involved in traffic guidance and in minor improvements to existing traffic facilities, such as removal of obstructions, laying of smoother pavements, narrower sidewalks where roadways are congested and sidewalks are not, easier curves at intersections, through modifications in sidewalk corners, are clearly justified where they will bring an appreciable measure of relief.

Zoning can be used to ameliorate traffic conditions by decentralizing traffic and by reducing the need for transportation. It must, however, be gradually applied and conservatively administered if it is not to impair seriously existing real-estate values and if it is to receive the necessary degree of support from public opinion. Relief to existing traffic congestion by zoning must always, therefore, be a slow process, a matter of decades if not of generations. Its major contribution to the solution of the traffic problem must be sought in its use to forestall prospective intensification of traffic congestion by preventing further overconcentration of traffic-producing enterprises in narrowly circumscribed areas. It has an important and constructive place in the long-run program, but its potentialities are limited in dealing with the congestion which already prevails. In congested areas of large cities major improvements are liable to involve great expenditures, because more land for street space can ordinarily be acquired only at prohibitive cost and in many locations is wholly out of the question, while the cost of construction of elevated or subsurface traffic ways is many times greater than the cost of the existing natural surface facilities. In many instances, however, the only alternatives are serious traffic congestion growing progressively worse as the city grows in population, a tremendously expensive program of major highway improvements, or traffic restriction. In most American cities adjustment is being made to the pressure of expanding volume of traffic by a compromise between these three.

For most, and probably for all, large American cities a program of providing in the congested areas ample facilities for all the traffic, whatever its type, which would offer itself if the facilities were there, would involve so staggering a cost that such a program would clearly be impracticable. It is clearly uneconomical also to tolerate the persistence of a degree of traffic congestion so great as to reduce substantially the traffic capacity of the streets. The long-run program of dealing with the traffic problem must necessarily provide both for extension of facilities and for restriction of traffic. The general sentiment in support of the free and unrestricted use of the public streets is powerful, and headway against it can be made only very slowly. Nevertheless, traffic restriction is inevitable. If it is not applied by traffic officials in accordance with a carefully designed plan, it will come about automatically and in greater degree through the suppression of traffic resulting from acute congestion.

To what extent in any particular situation the problem of traffic congestion should be met by extension of facilities and to what extent by restriction of traffic should be determined only after careful study of the situation and the application of as scientific a technique as can be developed for the comparison of the costs of the improvements with the economic costs of traffic restrictions if the improvements are not made. It is an unfortunate element in the situation that in most American cities the imagination of the public is more easily captured by projects for expensive ornamental driveways and boulevards in outlying sections of the city than by the more prosaic but usually much more urgent improvements which would serve to give substantial relief at the points at which traffic congestion is most acute. There are few American cities in whose congested areas an immediate and extensive program of major highway improvements planned to furnish an increase of traffic facilities is not economically justifiable. As land values rise fairly steadily in the traffic centers of large cities and as the process of replacing old and moderately sized buildings by new, more expensive, and higher buildings progresses, the cost of major improvements requiring the utilization of increased land space becomes greater, and the need for such improvements becomes more intense. In such cases delay is usually very expensive.

THE NEED FOR TRAFFIC RESTRICTION

The common practice, nevertheless, of measuring the extent of traffic facilities needed by the amount of traffic which would be present if the facilities were there is dangerous, because it fosters the delusion that traffic facilities are costless or that provision must be made, regardless of the cost, for all the facilities which traffic may demand. There is a scope for traffic restriction as one of the means of meeting the problem of traffic congestion. On purely economic grounds traffic restriction is always clearly preferable to the suppression and acute retardation of traffic which result from extreme traffic congestion. Up to a certain point, which differs with circumstances and can be determined only approximately and only by careful and expert survey of the situation, traffic restriction is more economical than the extension at great cost of existing traffic facilities. Traffic restriction would suppress traffic, but properly applied it would differ from the suppression of traffic resulting from acute congestion because it would not be accompanied by an impairment of the traffic capacity of the existing highway facilities, and because it would select the traffic to be suppressed in accordance with the economic importance of different types of traffic instead of arbitrarily.

In congested areas, what most needs economizing is not wear of the pavement but space utilization. The primary object of traffic restriction should be so to control the volume of traffic as to maximize the traffic capacity of the congested highways. There should be no restrictions on any highway, therefore, unless the

volume of traffic in the absence of restrictions is so great as to retard the speed of traffic movement substantially below the rate at which traffic capacity would be at its maximum for that highway. Where maximum traffic capacity can be maintained only by the application of traffic restrictions, the restrictions should be applied to various types of traffic and of carriers in inverse order to their utilization of road space per unit of transportation service rendered. In congested areas speed above the rate which brings maximum traffic capacity is to be regarded as an expensive luxury and to be given little extra consideration; inability to maintain that optimum speed is on the other hand an expensive nuisance and should be penalized. Where congestion is exceptionally acute, comfort and convenience of passengers must also become a minor consideration and must yield to movement of traffic if there is conflict between them. As traffic conditions ordinarily vary widely as between different periods of the day the restrictions also should be made to vary according to traffic conditions, being intensified at the traffic peaks and lightened or wholly removed at the traffic troughs.

Many estimates have been made of the relative efficiency in terms of space utilization per unit of transportation service rendered, of the different types of passenger carriers, but in no case that I have seen have these estimates taken into account all the factors which require consideration in estimating space utilization, or been based on tests made under conditions which permit of decisive determination of the most economic use in terms of passenger transportation to which a given stretch of highway can be put. What they do show conclusively enough is that in congested areas pedestrian traffic makes economical use of space per person per mile traveled, and that parking cars and loading and unloading of freight carriers at the curb and on the sidewalk is the most extravagant form of space utilization. They show also beyond reasonable doubt that private automobiles and taxis, with their average load in every city under two persons and a large fraction of that load consisting of chauffeurs, are much less economical users of congested road space per passenger mile than either motor busses or electric street cars. As between electric surface railways and motor busses, however, the evidence which is commonly brought to bear in favor of one or the other is contradictory and inadequate for conclusive determination of their relative economy as users of road space.

THE TEST OF UNECONOMICAL SPACE UTILIZATION

The proper test of relative economy in use of space has not yet been definitely worked out, and to some extent it must probably be a different test under different circumstances. The most common test applied to different types of passenger carriers using surface way is square feet of space occupied per seat. This is inadequate in a number of respects. Among the additional factors which should always be given consideration are: The possibilities of reasonable overload at traffic peaks; the speed per mile in conjunction with the corresponding minima of side clearance and safe braking distance; and the interference with other types of traffic. If vehicles are not permitted on congested highways if their width plus their necessary clearance exceeds the maximum width available on such highways per lane of traffic, width is a negligible factor and lineal feet tests are more conclusive than square feet tests.

The data presented in Table 5 indicate how different types of passenger carriers meet some of these tests of economy in space utilization.

TABLE 5.—*Street space utilization of various types of passenger carriers* [1]

[Data from Daniel L. Turner, consulting engineer, report to New York Transit Commission, May 9, 1923, and from other sources]

	Square feet per seat	Square feet per passenger	Lineal feet per seat	Lineal feet per passenger
Standard street car	6.63	[1] 3.32	0.79	[2] 0.39
Double-deck bus	3.28	[2] 2.19	.41	[2] .27
Ford touring car, 2 passengers			5.83	
Packard touring car, 2 passengers			8.33	
Pedestrian		1.96		1.25

[1] 100 per cent overload. [2] 50 per cent overload.

These data take no account of necessary clearances and stopping spaces, potential speed in heavy traffic, and interference with other traffic. They assume that the motor bus is capable of a 50 per cent overload above rated seating capacity, which is perhaps open to question. The double-deck bus with an uncovered upper deck in bad weather can not attain even its rated seating capacity, but the development of a satisfactory covered upper deck would remove this handicap. Test counts made by the Chicago Surface Railways Co., of the upper-deck passengers on Chicago motor busses during heavy rain showed in the count that 16 busses with partially-covered upper deck averaged 26.1 passengers on the upper deck as compared to an average of only 4.4 passengers on the upper deck of 48 uncovered busses at the same time on the same routes. Another count made during rain, snow, and sleet showed 10.9 passengers on the average on the upper decks of 22 partially covered busses as compared to an average of 2.8 passengers on the upper decks of 64 uncovered busses.[5]

In Chicago the average speed of busses in the Loop district was shown by tests to be 5.81 miles per hour, as compared to 6.21 miles per hour for surface cars, or about a 7 per cent superiority for the electric cars. Outside of the Loop district the busses averaged 11.87 miles per hour as compared to 11.63 miles per hour for street cars,[6] but in Chicago the busses outside the Loop operate on routes more favorable to speed than those of the street-car system, namely, parks and boulevards with rights of way, and with few intersecting streets. The evidence as to necessary clearance and stopping space and interference with other traffic is too contradictory and based too much on inadequate tests to have much weight one way or the other. The most conclusive test, if it were practicable, would be to test the space utilization unit of transportation service rendered, of the different types of carriers by putting through a selected mile of highway, during successive

[5] Computed from manuscript report of tests lent to the writer by the Chicago Surface Railways.

[6] Data from Report of John A. Beeler, consulting engineer, to New York Transit Commission, January, 1923.

hours and under similar conditions with respect to traffic guidance, cross traffic at intersections, etc., its maximum capacity of:

1. Motor busses alone.
2. Private passenger cars alone; and combinations in varying proportions, of—
   (a) Motor busses and electric street cars.
   (b) Motor busses and passenger cars.
   (c) Electric street cars and passenger automobiles.
   (d) Electric street cars, passenger cars, and motor busses.

In each case each vehicle should be loaded, or be presumed to be loaded, with its potential maximum load at rush periods. Such a test would disclose conclusively the relative space utilization of the different types of passenger carriers and the ideal use to which highways could be put when subject to high traffic pressure. Such a test would be an undertaking of large proportions, but when conclusions are based on surveys of actual traffic conditions, they can never completely meet the requirements of a scientific test, and, unless the results are overwhelmingly in favor of one type of carrier against another, must always be subject to contrary interpretations.

METHODS OF RESTRICTING WASTEFUL USE OF STREET SPACE

It is a commonplace of transportation economics that in practice there will not be the most economical utilization of the equipment of the carriers or of the highway facilities provided by the municipality unless the entire transportation service is operated as a unified whole under centralized direction. With competing types of transportation operating under independent management, duplication of traffic facilities on the part of the transportation agencies and consequent wasteful use of highway space are inevitable. It is especially important, therefore, that there be municipal restriction of wasteful use of congested highway facilities where the operation of competitive transportation service tends to weaken the private motives for the elimation of wasteful traffic operations.

The employment of space—utilization tests as the sole basis for the application of traffic restrictions would imply that the value of each unit of passenger transportation service, measured let us say in terms of the carriage of one passenger 1 mile, is uniform, and would leave no room for consideration of possible differences in the classes of persons served by the different types of carriers, in the relative convenience of the different facilities to passengers, or in the rates charged and the operating and other costs incurred per unit of service for the different carriers. It would be necessary, moreover, to avoid adopting any traffic restrictions within the congested area which would seriously disrupt the transportation system of the remainder of the urban area. Under existing conditions, however, the generally hostile attitude of the public toward traffic restrictions provides an adequate safeguard against the too hasty or too severe application of restrictions, and until the public is educated to appreciate the economic injury which results from traffic congestion, it is safe to predict that there will not be as much restriction of traffic as the prevailing conditions justify. But the acceptance by the public of parking restrictions, restrictions on freight traffic in congested areas during business hours, segregation of traffic, and other traffic restrictions which have in recent years been growing rapidly in extent, indicates that if the pressure of congestion becomes severe enough the public will submit in time to the painful necessities of the situation.

It has been suggested that a system of charges for the use of traffic facilities would be the most effective method of restricting traffic to proportions adjusted to existing traffic facilities, and this is the common method whereby the wasteful use of goods and services is restrained. Unless, however, there can be devised a system of charges to which traffic will be subject only as it uses the sections of highways which are congested and only at the periods of congestion, such charges, if heavy enough to exert any influence on the volume of traffic, will operate in the same degree to restrict traffic where there are still unused traffic facilities going to waste as to restrict it where the state of congestion justifies restriction. Except, perhaps, with respect to parking, it does not appear at all likely that any system of charges can be invented and made successfully to operate which will bear heavily on excess traffic while leaving unaffected the traffic for which the facilities are ample.

Traffic charges would tend to repress in greatest degree the marginal traffic, or that traffic which is just worth its cost to those engaged in it, and this is presumably the traffic whose repression would also involve the least economic loss to the community. But there is no assurance that this marginal traffic represents a more substantial proportion of the traffic on congested highways at the periods of congestion than of other traffic and that it is therefore the traffic whose repression would result in the greatest measure of improvement to traffic conditions. Where restriction of traffic is necessary, it is better to apply it in a flexible manner and in accordance with the needs of traffic rather than arbitrarily by means of traffic charges which fall alike on all users of highway space, regardless of whether that space is congested or not. To suppress traffic which does not contribute to traffic congestion is at least as uneconomic, measure for measure, as to permit traffic congestion to suppress traffic below the traffic capacity of the highways.

EFFICIENCY IN CONCRETE ROAD CONSTRUCTION

A Report of Observations Made on Going Projects by the Division of Control, Bureau of Public Roads

Reported by J. L. HARRISON, Highway Engineer

PART IV.—THE ORGANIZATION AND EQUIPMENT OF A CONCRETE PAVING OPERATION

IN PREVIOUS articles the fact has been developed that under a specification requiring a one-minute mix, 48 batches can be produced by a good mixer every hour. The common causes that prevent full production have been discussed, and there has been some discussion of the methods which have been observed to yield the largest output with the lowest labor and equipment supply. Most of these methods have been subjected to further study on jobs where they were adopted at the suggestion of the representatives of the Bureau of Public Roads in connection with efforts to improve production, and they are, therefore, both by observation and by practical experience with them, known to be efficient methods.

It remains now to show in some detail what equipment is actually needed and what minimum force is required in order to obtain full production if these methods are used, for, though full production is secured, this does not represent full efficiency if it is attained by the use of excessive equipment or labor. However, a statement of methods is not by itself an adequate basis on which to rest a personnel schedule. The operations which must be performed also influence labor requirements. As it is obviously impossible to deal with all of the minor variations in operations which affect the required amount of labor and equipment, only the standard operations will be discussed. But even with this limitation, there is some difficulty of approach to a statement of the personnel and equipment required, for there is no general uniformity in the meaning of even the more standard terms by which construction work is described, and unless the basis of a discussion of this sort is perfectly clear, misunderstanding may easily result.

Thus, in one State, the specifications for concrete paving are interpreted to mean that subgrade (commonly prepared a year or so in advance of paving) is at grade and that the correction of any divergence from this condition shall be paid for as a separate item—excavation. In other States the contractor accepts the subgrade "as is" and understands that the cost of corrections is a part of the cost of paving. The effect on the labor required for "paving" is apparent. In some States shoulder work and the general clean-up are included in the standard unit, "concrete paving," whereas in others shouldering and the clean-up are separate items. In some States a center joint is worked out over the parting strip. In others the pavement is permitted to crack over the parting strip, and in still others no center joint is used. Other items of this sort could be noted if they were needed to illustrate the fact that there are wide differences in the operations required under even so common a term as "concrete paving," as a result of which there are corresponding differences in the personnel and equipment required.

From the standpoint of the engineer, standardization in terminology may perhaps seem to be a matter of little consequence. In general, he feels that no matter how much is included in a given unit of construction, the contractor can make appropriate allowance for it, and that if the units are few the opportunity to claim compensation for extra work will be minimized. A little study of the actual effect of this practice, however, will serve to convince him that some advantages would accrue from standardization. Of these, possibly the greatest would be (1) a broadening of the field of compensation, and (2) the possibility of a more direct comparison of price levels. As matters now stand, the fact that the square yard of concrete pavement may cover all sorts of things not directly associated with its construction and that these will differ from State to State, makes it difficult for the contractor definitely to appraise the situation until he has acquired some familiarity with the correlated requirements and practices locally involved, standards of perfection in vogue, quality of inspection, etc. Thus, as an example, take the matter of requiring contractors to bid on the acceptance of subgrade "as is," as compared with treating the correction of irregular subgrade as a separate item. It is, of course, apparent that variations in the subgrade ordinarily will not be large, but their amount can not be determined except by a rather careful survey. It is also apparent that, because they are commonly small, the unit cost of handling the material which must be moved in correcting them is likely to be high. The contractor who knows local conditions, that is, the one who knows what standards of accuracy are customarily enforced, can bid with some safety on accepting the subgrade "as is," whereas the contractor who is unfamiliar with the local practice would find this a serious element of risk.

In a case observed during the past summer, the existing subgrade, over considerable distances, ran high to the extent of from 6 to 18 inches. On such a subgrade 28 feet wide, reduction to grade might involve moving nearly a cubic yard of material per foot of run—some 5,000 cubic yards to the mile. In this case, it is true that the reduction of the subgrade was paid for as excavation. Cases involving as much extra yardage as this are rare, but it is not uncommon to find subgrades varying in places from as much as 6 inches low to at least that much high, even where the subgrade must be accepted "as is." In such cases there is always a doubt as to what will be required. Some engineers will require that the differences be corrected, some will re-lay the grade line to more nearly fit the existing subgrade. It is not necessary to extend this discussion to justify the conclusion that this lack of uniformity in practice and governing requirements adds to the difficulty which the contractor necessarily faces in any attempt to broaden his field of activity, which is merely another way of saying that lack of standardization in the work covered by common engineering designations reduces competition.

OPERATIONS IN "LAYING CONCRETE PAVEMENT" DEFINED

This discussion will also serve to show that it is necessary to define even so common an expression as "laying concrete pavement" before there can be any certainty that it will mean to the reader what it means

to the writer or that the following conclusions as to equipment and personnel requirements, though they are based on extended field observations, will seem to be justified. Therefore the operations covered by the phrase "laying concrete pavement," as herein discussed, are definitely described as follows:

1. *Preparing subgrade.*—This covers all operations incident to converting a rough subgrade, which has previously been brought to the proper grade, to such shape and condition as is required for the placement of the pavement, but does not cover any work required in bringing the rough subgrade to the proper grade.

2. *Handling forms.*—This covers all work incident to taking up used forms, cleaning them, moving, setting, aligning, oiling, and otherwise working with the forms.

3. *Handling materials.*—This covers all work incident to unloading cars, storing or caring for materials, loading job transportation units, and unloading them into the mixer. It also covers the water supply.

4. *Hauling materials.*—All work of transporting materials and all work done on or in connection with the use and care of transportation equipment is included under this designation.

5. *Mixing.*—This includes the operation of the mixer and all work on the mixer.

6. *Finishing.*—All work of placing materials (puddling), finishing, covering, curing, etc., is included under this designation.

Miscellaneous operations, such as the placing of parting strips and reinforcing steel are not standard operations, that is, they are not part of the general operation of laying concrete pavement as it has been treated in these articles, but the effect on the labor requirements of these and other miscellaneous items will be discussed briefly.

It has been noted that the personnel and the equipment for a job depend on the methods in use and the efficiency with which these are carried out, as well as on the operations that are performed. It is therefore necessary at least to outline the methods on which a statement of personnel and equipment rests, just as it has been shown to be necessary to outline the operations covered. The preceding articles have made some reference to methods and such additional reference to them as has seemed necessary is made in presenting the following schedules of personnel and equipment. The methods on which these schedules are based have been selected from among those observed in practice on the various jobs where studies have been conducted, and most of them have been subjected to trial in connection with the efforts made on a number of jobs to increase production. They are the simplest and most direct methods that have been found, and while it is recognized that occasions may arise in which they will prove inappropriate, they at present appear to be the best that have been developed for this work. No job has been found on which all of these methods were in use, but it would appear that there is no basic reason to suppose that in combination they would be less efficient than they have been where observed in use, or where placed in use on recommendation of the bureau's representatives.

COMPLETING THE ROUGH GRADE

Whenever the rough subgrade is not at proper grade the first operation should be to reduce it to grade. The grade, as now staked, is commonly the bottom of the slab at the crown. The "proper grade" is somewhat below this,[1] at the elevation at which the quantity of material which must be taken out for setting the forms and for the thickened edges of the pavement, will be just sufficient to build the crown. If the rough subgrade is consistently high, but by moderate amounts, the blade grader offers the simplest and cheapest means of reducing it to the proper grade. The grader may be pulled by a 5-ton tractor and when so operated will cut away and throw aside excess material expeditiously unless the subgrade material is too rocky or unusually tough. It will not, however, correct a low rough grade. It is, therefore, a more common practice to use a plow and two or three fresnoes on this work, as these will serve equally well to remove high areas and to carry material to low ones. One thing, however, should be emphasized. The current practice of setting forms before the grade is reduced, is cumbersome, and needlessly expensive. It not only requires heavy hand trenching for the forms wherever the grade is high, but also the omission of a section of the forms every 100 feet or so to allow the fresnoes to reach the shoulders and as a result the haul is needlessly extended because all material must be moved through these openings rather than directly to the shoulders. Moreover, the material so handled is commonly wasted in piles, generally on one side of the road only, with the result that it must either be rehandled when the shoulders are worked out or be left to mar the appearance of the roadside.

The force required for this work naturally depends on the amount by which the subgrade varies from the proper grade. A common organization is one plow team and two fresno teams with drivers, a plow holder and a foreman. Where a blade is used the whole width of the subgrade has to be reduced, but when a fresno outfit is used, it is customary to reduce to grade only such a width of the subgrade as is needed for the pavement and for setting the forms. Even then the quantity of material to be handled is often so great that the above organization must be considerably increased, at least for short periods. But since it is advisable to maintain as nearly as possible the same force, these men at least should be regularly employed, and when they are not required on rough grading they can usually be used on shouldering and on the clean-up.

PREPARING THE SUBGRADE

The rough grade having been brought to proper grade (this being in fact a grading operation) the first operation incident to laying the pavement is to cut out for the thickened edge, at the same time cutting wide enough to take out most of the material that must be moved to allow the forms to be set. The proper tool for this work is a fairly heavy blade; and, while this can be drawn by horses, it is better to use a 5-ton crawler-type of tractor as the operating space required is less, and the usefulness of the tractor in general service about the job is greater.

The forms having been set, the width of the subgrade on which the pavement is to rest may be thoroughly broken up by a scarifier and trimmed to correct section by a first-class subgrader, surplus material being removed by hand or by fresno, depending on the accuracy with which the rough grade was finished. In performing this operation, the subgrade should be left from a quarter to a half-inch high and then lightly

[1] For a more complete discussion see Efficiency in Concrete Road Construction, Public Roads, January 1926, vol. 6, No. 11, p. 245.

rolled by a light (1½ to 3 ton) roller after which, to insure accuracy of cross section, the grade of the forms should be checked and the subgrader used again with the blades adjusted to cut to exact cross section. Finally, a modern heavy fine finisher (often known as a subgrade planer) should be attached to the mixer to be dragged along by the mixer whenever it moves If the subgrade is so dry or so solidly packed that it is not easily trimmed by the fine finisher, it should be heavily sprinkled under and about the mixer and whenever necessary, the puddlers should stand on the finisher while it is being moved.

These operations of subgrade preparation require the following equipment:

1 blade grader, heavy-duty, 8-foot blade.
1 caterpillar tractor, 5-ton.
1 scarifier.
1 subgrader.
1 fine finisher.
1 light roller.

The labor requirements are 1 tractor operator, who can act as subforeman; 1 blade operator; 2 laborers with the tractor; 1 roller operator; and 1 laborer at the mixer to take care of the fine finisher and perform miscellaneous tasks, particularly filling depressions in the subgrade, removing cuttings from the fine finisher and wetting the subgrade.

FORM SETTING

Form setting is a manual operation. No heavy equipment is required for it except, as noted above, that the blade grader should take out most of the material which has to be removed before the forms are set. The knack in setting forms is accuracy in preparing the bed on which they are to rest. This bed should preferably be cut a trifle low and topped with a layer of loose material, not over a quarter inch deep, on which the forms rest just high enough so that they must be tamped and worked a little to bring them to exact grade. A proficient laborer can trim out the bed to within a quarter of an inch of the correct level easily and rapidly. If an effort is made to trim exactly to grade, high spots are certain to be left with the result that sections of the form will have to be removed to work them down. On the other hand, if the bed is cut too low—a half inch or more below the correct level—the material under the form must be tamped. This may take the time of one or two extra laborers and there is the added disadvantage that it is seldom so thoroughly done that the forms can be depended on to hold grade.

If the practice of cutting the bed just below grade and setting forms on a thin layer of loose material is followed, 3 men—1 to cut the trench and 2 to set the forms—are all that are required to set and align 1,000 feet of forms a day. Beside this, 2 laborers are required to take up used forms and load them on the wagon in which they are hauled back and distributed to the form setters. A team and wagon is better and cheaper for this work than a truck. It can get over the shoulders and through the ditches better than the truck; and the greater speed of which the latter is capable on good roads is of little advantage in this work because of the time consumed in loading and unloading as well as the bad going. In spite of the fact that it is cheaper to use a team for this work, however, many contractors use a truck because the men do not like to be bothered with the care of a team which, of course, involves extra work after the regular day's work is over. Where there is no other horse-drawn equipment on the job, the best solution is to hire a reliable local man with his team. This relieves the contractor and his foremen of the necessity of looking after a single unit requiring attention after regular working hours.

The work of moving the forms commonly takes less than the full time of the above force; and it is, therefore, available for such other duties as cleaning and oiling the forms, for setting forms when this is necessary, or for any other miscellaneous duties that may be required of them. In addition to the laborers, a foreman is needed to keep things moving smoothly. As the form setting and the subgrading are closely related, it is well to put a good foreman over the two operations, allowing him to use the tractor operator as a subforeman in charge of subgrading operations in his absence.

In this connection a word may be said as to foremen. Some contractors want what they term working foremen—that is, foremen who work with the men doing much the same tasks and assisting generally in the ordinary work of the day. This is a poor practice. Keeping a dozen men effectively at work is task enough to demand the whole attention of any ordinary foreman and if high efficiency is to be attained in pavement construction, it will generally be helpful to make this clear to all foremen. They should understand that they are employed to keep the men under their direction at work and the work for which they are responsible moving smoothly and that, no matter how hard they may work themselves, unless they actually accomplish this, their value is lost. The practices here noted require the following equipment:

1 wagon.
1 team, 2-horse.

The labor requirement is as follows:

1 foreman.
1 laborer to cut trench for forms.
2 laborers to set forms.
2 laborers to remove forms.
1 teamster.

HANDLING MATERIALS

The handling of materials has been discussed in a previous article.[2] Generally speaking, the most satisfactory material plant is an oil or gasoline crane of the crawler type with a ¾-yard bucket (a 1-yard bucket is needed if a high rate of production on the basis of a 6-bag batch is to be had) and a steel bin equipped with a modern fast-dumping, batch-measuring or weighing device. Steam-driven equipment, whether rollers, cranes, or mixers, is out of date and expensive to operate. It commonly requires an extra man to fire each unit, often a team to handle the water supply and sometimes another to deliver the coal; and time is lost in taking on water and often in taking on coal also. The time worked per day is, for this reason, commonly less than can be had from gas equipment and the labor and auxiliary equipment required is commonly more expensive. With most types of heavy equipment there is, to offset these differences, no corresponding increase in production or decrease in any other item of the operating expenses.

[2] Efficiency in Concrete Road Construction, PUBLIC ROADS, January, 1926, vol. 6, No. 11, p. 242.

At the cement house, a belt conveyer should be used for elevating the sacks to a point where they can be emptied into hoppers from which the cement can be discharged into the delivery equipment. A sack cleaner and a sack baler should also be installed here, their operation requiring the time of one man. If the cement is sent out sacked, the sacks must be collected and returned to the cement house, a considerable part of the time of one man and a light truck driver often being used on this work. To what extent this is an additional item of expense depends somewhat on whether other conditions surrounding the job are such that a service truck with driver and helper must be maintained in any event. As sending the cement out sacked is not an efficient method of handling it, no provision is made for it in the minimum labor and equipment schedules.

At the mixer the trucks must be turned around before they can be backed to the mixer and dumped. This may be done by backing the trucks but, as on high fills or in deep cuts the room available is limited, it has generally been found more practical to use a turntable. One man is required to operate the turntable and from time to time the tractor is sent back to move it forward out of the way of the mixer.

Turntables are commonly designed to accommodate only one style of trucks. This is regrettable as it often is to the advantage of the contractor to hire a few extra trucks and it is not always possible to procure these, particularly in the heavier types, with a wheel base of the same length as those regularly used. As the practices on any well-organized job become so well established that the initiation of a nonuniform practice in handling a few trucks tends toward disorganization, available equipment is not infrequently rejected, merely because it can not be handled on the turntable. It should be a simple matter to equip the larger sizes of turntables with an easily controlled truck-positioning device which would make it possible to use the turntable in handling trucks of a number of different sizes. If this were done, the contractor's problem in hiring extra transportation to meet extra-long haul would be considerably simplified.

At the mixer, one man is needed to help in dumping the trucks. The end gate must be released to allow the truck to discharge its load and after the load is discharged the gate must be closed and locked. Often a little material not deposited in the skip must be salvaged.

For handling the water, which is, of course, one of the materials, a pump is required. The supply of pipe will depend entirely on local conditions but as a general practice at least 20,000 feet of 3-inch pipe with fittings and a take-out connection for every 300 feet of line should be available. If take-out connections are provided every 300 feet the equipment for water delivery will include two lengths of 2-inch pressure hose about 175 feet long to feed the mixer and, to prevent loss of time in changing hose, the mixer should be provided with a double hose connection so that the second hose can be connected before the first is disconnected.

The pipe is commonly laid before mixing starts and during the move from one mixer set-up to the next. When laid in this way, labor and transportation equipment which otherwise might be idle or assigned to more or less nonproductive work are used. Though pipe must be maintained in position for some days after the concrete is placed in order to furnish water for curing, it generally is possible to synchronize removal and relaying operations with the mixing operation, at least to such an extent that the amount of work to be done on the pipe line when a move is made is materially reduced. In the interest of prompt moving the relaying should be entirely completed before the move is begun. To make this possible the quantity of pipe and fittings which will be required should be calculated before the job is started and the correct quantity of pipe should be sent out. If this is done, removal and relaying can be so handled that the pipe line will never delay the moving; and when handled in this way, the time of two men is all that is required. Generally no extra transportation is needed as the team used for hauling forms can ordinarily find time to move the pipe also.

Finally, to keep the supply of all materials running smoothly it is well to place this work under the direction of a good foreman. It is one of the outstanding important elements of the job and should be carefully supervised.

Handling materials (including water delivery) under these practices, most of which have been more fully discussed in previous articles, will require the following equipment:

- 1 crane, crawler type, ¾-yard bucket.
- 1 steel hopper, with modern batch-measuring or weighing device.
- 1 cement house, with cement loading bins.
- 1 belt conveyor for cement house.
- 1 sack cleaner.
- 1 sack baler.
- 1 pump, 100-gallon capacity at 400 pounds pressure.
- 20,000 feet of 3-inch common steel pipe with fittings.
- 350 feet of 2-inch pressure hose (in two sections).
- 1 turntable.

The labor required is as follows:

- 1 plant foreman.
- 1 craneman.
- 1 hopper operator.
- 1 extra man to help unload cars.
- 3 cement handlers.
- 1 laborer to clean and bale sacks.
- 1 pump operator.
- 2 laborers to handle and lay pipe.
- 1 turntable operator.
- 1 truck dumper.

MATERIAL DELIVERY

The equipment required for material delivery and transportation has been fully discussed in another article.[3] As this is the most variable element on a paving job, it must be determined for each project. Besides the transportation equipment each job should have a reasonably well-equipped repair shop with a skilled mechanic in charge to keep the equipment in good running order. Naturally, as such a man may be expected to spend most of his time working on the trucks, he should be particularly well trained in caring for these, but he should know something of other types of equipment as well. On most jobs the mechanic should have a helper who may well know something of blacksmithing.

There are a few key positions on any sort of work, where it is outstandingly expensive to hire cheap men.

[3] Efficiency in Concrete Road Construction, PUBLIC ROADS, December, 1925, vol 6, No. 10, p. 220.

The job mechanic holds one of these positions. The craneman holds another, the mixer operator another. In any of these positions the best man that can be obtained is not too good. As high production always means extra-hard work for these men, a wage scale based at least in part on the production obtained is always worthy of consideration. A scale based wholly on production would from the contractor's standpoint, be perhaps even more desirable, but the objection to this lies in the fact that superintendence quite generally is the weakest element in the contractor's organization, and these men are not in a position to develop high production if the superintendence is weak. They can only respond wholeheartedly when good superintendence makes high production possible. In view of the common occurrence of poor superintendence, it is unfair to ask such men to work wholly on a production basis for the risk they then assume is too great. A far better and fairer way is to pay the standard wage and offer a bonus for production over some specified quantity.

EQUIPMENT AND LABOR REQUIRED IN MIXING

Efficiency in mixing requires a number of things. The paver should have ample power. It should be able while mixing to move and at the same time drag a heavy fine finisher, and also to start the skip and the discharge as close together as the operator can move the levers. Moreover, the real test of a mixer is not whether it can do these things when new but whether it can do them after it has been in service two or three seasons. This requires a good power plant. The mixer should be able to move any reasonable distance, 10 miles or more, under its own power without stopping to cool bearings or clutches. This is essential as a tractor is not always at hand to drag it from one location on the job to another.

Too much care can not be taken by a contractor who is buying a new mixer in determining what time is required in emptying the skip after it is in a vertical position. A good 5-bag paver will ordinarily clear the skip in less than 5 seconds, yet one recently observed by the writer took over 30 seconds to complete this operation. Poor blade design seemed to be at the bottom of the trouble in this case, and the slow charging and discharging cut production from a possible 48 to about 34 batches an hour. No contractor can afford to own such a mixer. The time required to start the discharge after the time bell rings should be determined and the time required for discharging should be examined. It should be remembered, also, that there is an appreciable difference between the time required to discharge a batch of sloppy concrete and that required to discharge a batch of the consistency now commonly used in highway work. The latter runs more slowly in the chute, piles up in the generally inadequate bucket, and finally backs up into the chute with the result that the discharge time is increased. The rate of discharge and the rate at which the skip is raised depend somewhat on the speed at which the engine is running. What the buyer wishes to know is how fast these operations take place under normal conditions and for that reason he should be sure that the drum speed is normal—about 15 revolutions a minute—and that concrete of standard consistency is being mixed when checking performance in these respects.

Aside from the mechanical operation of the mixer, which is, of course, vital to high production, purchasers of new machines would do well to give thought to the quality and workability of the concrete produced. In this particular there is, perhaps, as much difference as there is in mechanical efficiency. Smooth, well-mixed concrete is easier to work than brash, undermixed concrete. Engineers now give little thought to any phase of this matter except the slump. But a given slump may be had in either of two ways: (1) By thoroughly mixing a proper volume of water with a given amount of cement and aggregate; and (2) by undermixing the same aggregate and cement with excess water. If this latter is the case the resulting concrete is generally admitted to be of relatively poor quality. That the use of excessive water accompanied by undermixing is a frequent result of current specifications is evidenced by the large number of jobs on which the typical result of this practice may be observed. The result referred to is the rising of water to the surface of the newly-laid concrete in such quantities that it drips over the forms often for an hour or so after the concrete is placed. Where the water content is correct and the mixing is well done, no water will drain over the edge of the forms. If the contractor feels that this is the engineer's business, it may be well to suggest that his self-interest should dictate the selection of a really good mixer for the very good reason that a well mixed concrete is easier to handle and finish than an undermixed concrete.

The time is coming, and that at no distant date, when the present ineffective treatment of the mixing problem will be replaced by some practical and direct method of insuring thorough mixing and a correct water content. There are, then, a number of reasons that should influence contractors to protect themselves by purchasing only those mixers which, within the specified time, will turn out a really well-mixed batch. There are such mixers and they can be readily distinguished by observing the concrete mixed in them for one minute to a slump of an inch or less (1) as to the ease with which it can be finished and (2) whether water rises to the surface and runs off over the forms. If the mixing has been well done, the finishing will be relatively easy, the surface will require no final correction and no water will run off over the forms.

The equipment requirement for mixing is one mixer and the labor requirement is one operator.

FINISHING EQUIPMENT AND PERSONNEL

The first operation in connection with finishing is the spreading of the concrete—commonly called puddling. If the mixer operator is really well trained he will spread the mixed concrete so well that two puddlers will be able to do all the spreading necessary and do the spading along the forms as well. No heavy equipment is needed in connection with this operation.

The next operation is shaping the crown and working and compacting the mass, which is now almost entirely done by machine finishers. A sliding finisher using two sliding screeds does this work outstandingly well. When operated over concrete of proper and uniform consistency, the surface produced is conspicuously uniform. Following immediately behind this machine one man with a long-handled float can readily wipe out the screed marks, and check the surface with a 10-foot straightedge. The finish obtained in this way is rapid and so accurate that it is seldom necessary to fill a low spot or to take off a high spot in order to meet the most rigid requirements now in force as to surface finish. The final belting follows the checking of the

surface with the straightedge, and, for this operation, the finishing-machine operator ordinarily can be called on to aid the finisher as his time is seldom taken up fully in running the finishing machine. Covering the pavement with burlap or other temporary cover commonly requires two men; the earth covering commonly requires two more; and watering another.

The equipment required for finishing is, then:

1 finishing machine, double sliding screed.

The labor requirement is:

- 2 puddlers.
- 1 finishing-machine operator.
- 1 finisher.
- 2 laborers to spread canvas.
- 2 laborers to cover concrete with earth.
- 1 laborer to sprinkle the concrete.

In addition to the labor requirements above discussed, common practice and good judgment dictate the employment of a superintendent, a timekeeper, a watchman, and a water boy. In the consideration of the labor and equipment required in laying the pavement, however, these are not included because their duties extend to the whole job, and they belong, therefore, to the job overhead rather than to the labor structure of any unit of the job.

MISCELLANEOUS LABOR AND EQUIPMENT REQUIREMENTS

A center joint is now quite commonly required. Where it is used, a line of reinforcing steel is often placed along each edge. Sometimes other reinforcing is also used. Placing the center joint and the two lines of reinforcing steel generally requires the time of

TABLE 1.—*Major equipment used on typical concrete paving jobs during 1925 compared with the most efficient equipment combination*

Operation	Most efficient equipment combination	Equipment combinations on typical jobs																
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Rough grading:																		
Plow	1			1		1									1			2
Fresno	2			1														3
Wheel scraper									1									
Maney grader												3						
Truck															1			
Fine grading:																		
Blade grader	1	1		1	1	1	1	1	1	1		1	1	[1] 1	2	1	2	1
Tractor	1	1	1	1	1	1	1	1	1	1	1	1			2	1	1	1
Scarifier	1				1							1			1	1		
Subgrader	1	1	1	1		1	1	1		1	1				1		1	1
Fine finisher	1	1			1							1						
Roller	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Fresno, team		2	1	1	2	2						[2] 4			1	1	2	2
Wagon		1															2	
Drag					1													1
Handling forms:																		
Forms, lineal feet	5,000	4,000	2,800	3,200	2,500	2,100	2,500	5,000	2,000	4,000	3,000	3,000	3,000	[3] 1,000	3,200	3,000	3,600	4,000
Wagon, team	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1
Handling materials:																		
Crane	1	1	1	[4] 1	1	1	1	1		1	[4] 1	2	2		1	[4] 1	1	1
Hoppers	1	1	2	1	1	1	1	1		1	2	2	1		1	1	1	1
Conveyor (for cement)	1						1											
Cement house	1	1	1	1		1	1	1	1	1	1	1		1	1	1	2	2
Pump	1	2		1	1	1	1	1	1		1	1			2	2	2	
Pipe, lineal feet—																		
3-inch	20,000																	
2½-inch				15,000		13,200												
2-inch		17,000	15,000	12,000	26,400		15,840	18,480		1,000	15,840	31,680	10,560		15,840	42,240	52,580	20,000
1½-inch			10,000															
Size unknown									15,840									
Hose, lineal feet—																		
2-inch	350	125	200							150	150	150		300		300	200	
1½-inch				150	200	200	400	250	(5)				200		150			270
1-inch			200	150													450	
¾-inch																400		
Size unknown																		200
Turntable	1	1	1		1	1	1	1	1						1	1		
Sack cleaner	1	1		1		1	1	1	1									
Sack baler	1			1		1	1	1	1									1
Loader									2					1				
Stacker									2									
Hauling materials:																		
By truck—																		
Trucks	20	20	16	[6] 8	11	12	[6] 8	[6] 6	26	[7] 12	[8] 13	21	[9] 6	[6] 4	40	26		
Tractor							1											
Service truck	1	4		1	1								1		1	2		
By industrial railway—																		
Locomotives																	[10] 18	[11] 3
Cars																	227	52
Batch boxes																	239	104
Track, miles																	[12] 14	[13] 6
Switches																	15	5
Service trucks																	1	1
Mixing:																		
Mixer	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mixer crane																	1	1
Finishing:																		
Finishing machine	1	1	1	1	1	1	1	1			1	1	1		1	1	1	1
Burlap truck				1														
Miscellaneous:																		
Repair shop	1	1		1	1											1		
Straw wagon					1								1		1	1		
Lighting plant							1										1	
Water truck				1														

[1] Horse-drawn.
[2] Slip scrapers.
[3] Used at center only; curb at side.
[4] Steam crane.
[5] Length unknown.
[6] 2-batch trucks.
[7] Nine 1-batch and three 2-batch trucks.
[8] 3-batch trucks.
[9] 3 and 4 batch trucks.
[10] Ten 8-ton, one 6-ton, and seven 5-ton gas locomotives.
[11] 8-ton locomotives.
[12] 7 miles of 25-pound and 7 miles of 20-pound track.
[13] 25-pound track.

two men. If the edges are rounded and a center joint is formed over the parting strip, one or two extra men may be required. Working the center joint, however, is of no apparent value as the concrete cracks by contraction over the parting strip within a few hours after it is placed and the black center line, now widely used to divide traffic, fills and obliterates it. Where the worked joint is used, the final result is about the same, except that, on the whole, the center band put down over the crack ordinarily presents the neater appearance.

The common tendency of pavements to develop transverse cracks together with the fact, increasingly to be observed as pavements grow older, that where no expansion joints are used, the buckling which occurs during the summer months tends constantly to increase the roughness of these pavements, leads to the observation that transverse joints are not now used to the extent that they should be. At one time they were in common use, but they fell into disuse because they were expensive to install and because it was difficult to obtain a uniform finish across them. The sliding finisher has eliminated at least the more important part of this difficulty. It is now possible to finish over such a joint without the slightest difficulty and with full

TABLE 2.—*Personnel employed on typical concrete paving jobs during 1925 compared with personnel required with most efficient equipment*

Operation	Personnel required with most efficient equipment combination	Personnel employed on typical jobs																
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Rough grading:																		
Grade foreman	1		1															
Plowholder	1																	
Teamsters	2			2					1			5						1
Laborers									1									
Fine grading:																		
Subcontractor									1									
Foreman		1	1	1	1	1	1	1	1	1	1	1			1	2	1	1
Tractor operator	1	1	1	1	1	1	1	1			1	1			2	1	1	1
Blade operator	1				1	1	1	1	1			1	1	1	2	1	1	1
Roller operator	1	1	1		1	1	1	1	1	1	1	1	1	1		1	1	1
Subgrader operator	1																	
Teamster		2		1	2	2		1								1	1	2
Laborer	2	9	13	5	10	13	11	13	7	1	18		12	7	11	43	7	10
Handling forms:																		
Foreman	1	1	1	1		1	1	1	1		1	1				1	1	
Teamster	1	1	1	1	2	1	2	1	1	1				1	1	1		
Laborer, to set forms	3	2		1	2	2			2	2	3	2	5	2	2	5	2	2
Laborer, to strip forms	2	2			2	2			2	2	3	2	5	2	2		2	2
Laborer			4	3	2	1	3	4		2		2		2	1	1	2	2
Handling materials:																		
Plant foreman	1	1		1		1	1	1	2		1	1	1					
Crane operator	1	1	1	1	1	1	1	1		1	1	3	1		1	1	1	1
Crane fireman				1			1	1			1					1		
Hopper operator	1	1	1	1	1	1	1	1		5	2	2	3	4	2	2	2	2
Cement handlers	3	5	1	5	3	6	3		5	3	4	3	2	1	2	2	5	6
Bag dumper			3			2	2	3	3	3	4				2	2		
Bag baler	1		1	1		1	1	1	1									1
Pump operator	1	1		1	1	1	1	1	1		1	1			1	1	2	1
Laborer on pipeline	2	1					2				1	1			1	1	1	1
Turntable operator	1	1	1		1	1	1	1	1									
Truck dumper	1	1		1	1	2	1	1	1	2			1	1	1	1		
Laborer	1	1	2	3	1	1		14	1			2	5	6	1	2	1	5
Batch box handlers																	2	3
Hauling materials:																		
By truck—																		
Foreman		1										1						
Mechanic	1	1	1	2	1		1		1							1		
Helper	1	1		1														
Drivers, delivering material	[1] 12	20	11	[2] 8	11	12	[2] 7	[2] 6	16	12	[3] 11	16	[4] 5	[2] 4	40	36		
Truck checker																1		
Service truck driver		2		1	2								2		3	3		
By industrial railway—																		
Foreman																	1	1
Locomotive engineers																	10	3
Brakemen																		3
Switchmen																	1	
Mechanic																	2	1
Mechanic's helper																	2	
Laborer																	2	
Truckmen																	3	10
Tractor operator																	1	
Service truck drivers																	5	1
Mixing:																		
Foreman		1										1			1	1	1	
Mixer operator	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Mixer crane operator																		1
Finishing:																		
Foreman				1		1		1										1
Puddler	2	3	3	2	3	2	2		3	4	4	2	3	4	2	3	3	4
Finishing machine operator	1	1	1	1	1	1	1	1	1		1	1	1		1	1	2	1
Laborer, to finish concrete	1	3	4	2	3	6	2	3	2	2	2	2	3	3	3	4	2	2
Laborer, to spread canvas	2		2	2	1		2				3		2			2		2
Laborer, to cover concrete	2				2		2										3	
Laborer, to sprinkle concrete	1	2	2			5	6	1	4		3						2	
Laborer, to spade concrete				1	1									2	2	2		
Laborer		1		4					2	4		3	4		1	1	1	
Miscellaneous:																		
Superintendent	1			1		1	1	1	1			1			1		1	1
General foreman					1			1	1		1		2	4	1			
Timekeeper	1			2		1	1	1	1			1		1	1		1	1
Watchmen	1	1	1	2	2	2		1	1	1			2	1	1		1	1
Waterboy	1			1			2	1							1	1		1
Steel setter			1							3	6		1	2				
Joint material setter		1	1		1	1	1	1				1			1	1	1	4
Total (without drivers or miscellaneous)	42	52	47	49	48	58	53	56	48	35	57	40	53	38	47	90	64	71

[1] Average number for season. [2] 3-batch trucks. [3] 2-batch trucks. [4] 3 and 4 batch trucks.

assurance that high joints are wholly unnecessary. Moreover the use of joints need not at all reduce the rate of pavement production. An extra man, sometimes two extra men, will be required if expansion joints are used and some extra time is required in finishing, because the joints must be cleaned off carefully on top and along the ends, but as no other difficulties need now attend their use and as pavements where they are used appear to maintain their smoothness better than the jointless pavements, it is probable that their use will become more general.

The labor and equipment requirements here scheduled are believed to represent the minimum for full production. They are shown in relation to the labor and equipment used on a number of the actual jobs studied by the bureau in Tables 1 and 2; and a comparison of the minimum requirements as presented in this article (column 1 of both tables) with the jobs listed will suggest that better superintendence can reduce the labor and equipment used.

For the more perfect understanding of the labor table it may be well to remark that on a large percentage of the jobs on which statistics have been taken, the methods in use so intimately associated rough grading and fine grading that a definite separation was impossible. It was often found, too, that a good deal of the labor was hired to perform general operations as directed; that is, it was not constantly assigned to a specific task. For purposes of comparison, the totals shown omit truck drivers hauling material—an item that should vary with the length of haul—and miscellaneous positions such as the superintendent, timekeeper, water boy, etc. By this means a more direct comparison of the labor used on the operations discussed above is possible. It will, of course, be noted, that the major variation is in the grading. This is unavoidable.

One other matter deserves mention here, namely, that in many of the operations incident to laying a concrete pavement the labor requirement is fixed; that is, it can not be reduced even though the rate of production falls off. Thus, at the material plant, a craneman, a helper to assist in unloading cars, a hopper operator, and three men handling cement appear to be an absolute minimum. The equipment can not consistently be operated with less than this force even if production falls to 100 feet a day. On the other hand, some members of this force are not working to capacity even when the 5-bag paver is running at 48 batches an hour. Much the same is true of most of the other operations. The subgrade crew, for instance, requires a tractor operator, a roller operator, and at least two men, no matter how low production falls, because the equipment can not be operated with less. The mixer can not be operated by less than one man and the finishing can hardly be reduced below a man on the finishing machine and one on the float. There is no need to continue the recital of these minimum requirements to confirm the statement made in other articles of this series that cutting down the number of batches per hour (as is done whenever the mixing time is extended to 1¼, 1½, or 2 minutes) raises the cost of paving because neither the investment in equipment nor the amount of labor employed can be correspondingly reduced. Rather the path toward lower cost lies along the line either of increasing the size of the mixer or of reducing the time of mixing. By either process a closer approach can be made to the full utilization of the capacity of the men and equipment used in the secondary operations.

"The men don't seem to be working a bit harder," remarked a contractor when production on his job had been raised from an average of about 63 feet an hour to an average rate of nearly 100 feet an hour. That was visibly true. The difference was simply in the fact that they were wasting less time. How much further this would have been true remains to be seen. It is, however, apparent that a high-grade mixer running at the rate of about 15 revolutions a minute can turn out first-class concrete in a minute. Experiments are under way to determine whether, if the speed is run up to about 20 revolutions per minute, the mixing time can be reduced proportionately and still produce concrete of equal merit. If so, the mixer cycle might be reduced to about 60 seconds with the result that 60 batches an hour would represent full efficiency for a 5-bag mixer. The studies which have been made suggest that it probably would be possible for the correlated equipment (except the crane) to meet this rate of production with almost no change in the amount of labor employed. Further study, however, is required before any final conclusions as to this matter can be drawn.

BOND BETWEEN CONCRETE AND STEEL

"Studies of Bond between Concrete and Steel," by Duff A. Abrams, has just been published as Bulletin 17 of the Structural Materials Research Laboratory, Lewis Institute, Chicago. Bond tests were made by applying a pull on one end of 1-inch plain round steel bars embedded axially in 8 by 8 inch concrete cylinders; parallel compression tests were made on 6 by 12 inch concrete cylinders. The concrete covered a wide range in quantity of mixing water, cement, and size and grading of aggregate. Tests were made at ages of 7 days to 1 year; 735 pull-out bond tests and 735 parallel compression tests were made.

The principal conclusions from the tests are:

(1) Slipping of the bar began at a bond stress of about 10 to 15 per cent of the compressive strength of the concrete, but considerable additional load was taken before the ultimate bond resistance was reached.

(2) An end slip of bar of 0.0005 inch occurred at 55 to 60 per cent of the maximum bond. For mixtures leaner than 1 : 1, the maximum bond was about 24 per cent of the compressive strength of the concrete and came at an end slip of about 0.01 inch regardless of the characteristics of the concrete.

(3) Bond and compressive strength increased with age of the concrete from 7 days to 1 year. For 1 : 5 concrete of water-ratio 0.88, the bond at 1 year was 134 per cent of the 28-day value and the compressive strength was 148 per cent.

(4) Bond responded to changes in water-ratio of the concrete in much the same way as compressive strength; increase in water-ratio due to use of wetter concrete, less cement, or an excess of fine aggregate, resulted in material reductions in both bond and compressive strength.

(5) For mixtures richer than 1 : 1 the bond fell off probably due to the greater volume changes during hardening, which is characteristic of such mixtures.

(6) The use of 4 per cent of the 28-day compressive strength of concrete as the working stress in bond for plain bars, as specified by the joint committee, is justified; this gives a factor of safety of about 2½ to 3 against first slip.

(7) The use of crude oil to replace mixing water, in general, caused a reduction in both bond and compressive strength of concrete due probably to the lubricating effect of the oil. Replacing cement with hydrated lime also decreased the compressive strength and bond about 1.2 per cent for each 1 per cent of hydrated lime in terms of volume of cement or about 2 per cent for each 1 per cent by weight.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORT

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.

DEPARTMENT BULLETINS

No. 105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136. Highway Bonds. 20c.
220. Road Models.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314. Methods for the Examination of Bituminous Road Materials. 10c.
*347. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370. The results of Physical Tests of Road-Building Rock. 15c.
386. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387. Public Road Mileage and Revenues in the Southern States, 1914.
388. Public Road Mileage and Revenues in the New England States, 1914.
390. Public Road Mileage and Revenues in the United States, 1914. A Summary.
407. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
*463. Earth, Sand-Clay, and Gravel Roads. 15c.
*532. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*583. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*660. Highway Cost Keeping. 10c.
670. The Results of Physical Tests of Road-Building Rock in 1916 and 1917.
*691. Typical Specifications for Bituminous Road Materials. 10c.
*704. Typical Specifications for Nonbituminous Road Materials. 5c.
*724. Drainage Methods and Foundations for County Roads. 20c.
*1077. Portland Cement Concrete Roads. 15c.
*1132. The results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.
1216. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.

* Department supply exhausted.

No. 1259. Standard Specifications for Steel Highway Bridges; adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road work.
1279. Rural Highway Mileage, Income and Expenditures, 1921 and 1922.

DEPARTMENT CIRCULAR

No. 94. TNT as a Blasting Explosive.
331. Standard Specifications for Corrugated Metal Pipe Culverts.

FARMERS' BULLETINS

No. *338. Macadam Roads. 5c.
*505. Benefits of Improved Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *727. Design of Public Roads. 5c.
*739. Federal Aid to Highways, 1917. 5c.
*849. Roads. 5c.
914. Highways and Highway Transportation.

OFFICE OF PUBLIC ROADS BULLETIN

No. *45. Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.

OFFICE OF THE SECRETARY CIRCULARS

No. 49. Motor Vehicle Registrations and Revenues, 1914.
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
63. State Highway Mileage and Expenditures to January 1, 1916.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
161. Rules and Regulations of the Secretary of Agriculture for Carrying Out the Federal Highway Act and Amendments Thereto.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 20, D- 4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 10, No. 5, D-12. Influence of Grading on the Value of Fine Aggregate Used in Portland Cement Concrete Road Construction.
Vol. 10, No. 7, D-13. Toughness of Bituminous Aggregates.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

JANUARY 31, 1926

STATES	FISCAL YEARS 1917-1925			FISCAL YEAR 1926									BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
	PROJECTS COMPLETED PRIOR TO JULY 1, 1925			PROJECTS COMPLETED SINCE JUNE 30, 1925			*PROJECTS UNDER CONSTRUCTION			PROJECTS APPROVED FOR CONSTRUCTION				
	TOTAL COST	FEDERAL AID	MILES	TOTAL COST	FEDERAL AID	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	$ 5,970,097.71	$ 2,863,197.86	611.8	$ 8,315,672.36	$ 3,970,792.98	473.7	$ 7,310,919.97	$ 3,550,765.85	355.6	$ 1,086,634.09	$ 498,492.42	28.2	$ 3,466,205.89	Alabama
Arizona	9,580,133.43	5,016,119.94	613.8	1,041,126.35	636,703.27	92.2	1,217,174.81	805,183.26	88.7	176,977.10	108,150.70	26.7	3,051,091.83	Arizona
Arkansas	13,310,190.08	5,380,181.73	1048.9	3,508,401.67	1,540,533.11	189.5	5,937,644.37	2,851,698.28	371.6	653,819.17	294,714.62	44.9	1,538,676.26	Arkansas
California	22,346,175.99	10,719,249.61	894.8	2,664,358.92	1,206,974.63	72.4	11,889,525.68	5,873,082.11	356.0	341,395.01	133,340.26	6.3	4,140,198.39	California
Colorado	11,876,703.94	6,067,814.34	651.2	1,029,861.87	530,202.26	41.7	4,369,258.70	2,193,804.29	234.1	464,225.60	260,348.34	25.2	3,273,642.77	Colorado
Connecticut	4,558,639.29	1,819,368.66	101.6	750,965.91	250,212.14	13.4	1,901,818.16	590,259.68	29.1	238,929.61	62,777.95	3.7	1,611,062.57	Connecticut
Delaware	4,281,559.81	1,496,190.65	107.1	455,744.13	212,544.95	12.3	980,042.66	388,784.75	22.7	445,559.65	9,000.00	10.5	367,537.65	Delaware
Florida	2,959,273.72	1,405,487.97	36.3				11,039,134.35	5,071,300.29	295.5	635,098.94	207,255.00	13.8	1,400,910.74	Florida
Georgia	20,156,002.37	9,406,366.46	1478.3	2,979,105.82	1,447,535.03	181.5	11;103,588.50	5,240,139.13	691.7	927,564.99	459,146.55	71.5	1,878,765.83	Georgia
Idaho	9,394,676.80	4,815,332.26	600.1	735,647.37	484,367.73	47.1	2,651,708.09	1,633,247.23	183.4	471,051.34	255,404.45	17.0	1 371,275.33	Idaho
Illinois	40,010,481.10	18,640,076.28	1236.2	933,608.56	447,871.38	32.1	8,398,091.85	4,076,691.58	285.3				6,667,558.74	Illinois
Indiana	13,639,172.65	6,562,455.68	422.1	1,195,563.59	573,819.54	47.0	17,936,040.96	8,415,742.71	487.0	543,575.62	269,346.52	16.6	2,382,990.55	Indiana
Iowa	27,272,285.21	11,107,492.99	1996.9	782,462.52	320,365.06	36.5	7,838,501.88	3,526,869.59	476.8	1,184,561.72	572,403.90	140.3	3,958,431.46	Iowa
Kansas	26,399,695.77	9,755,273.32	831.4	3,949,959.30	1,760,737.02	233.9	10,389,649.37	4,283,091.36	500.3	2,831,782.29	710,832.29	152.5	2,954,477.01	Kansas
Kentucky	14,832,324.28	6,205,994.59	584.9	3,194,286.55	1,218,841.98	84.6	7,435,186.56	3,400,478.36	313.6	272,730.33	119,468.16	9.0	2,268,025.91	Kentucky
Louisiana	11,939,424.97	5,279,870.86	927.6	1,079,810.60	503,534.86	68.9	3,283,985.29	1,591,576.56	180.4	617,313.13	308,656.55	25.5	1,588,769.17	Louisiana
Maine	8,174,281.31	3,907,870.33	281.4	249,291.85	123,602.05	9.8	2,046,840.72	825,486.82	66.2	188,780.85	94,390.42	8.3	1,513,478.38	Maine
Maryland	8,132,506.90	3,849,383.15	234.4	1,290,368.13	576,326.77	41.8	1,840,919.15	838,622.00	99.2				660,725.08	Maryland
Massachusetts	14,047,656.22	5,467,661.28	300.6	751,829.45	271,111.11	20.4	6,087,949.31	1,591,752.67	80.4	979,762.40	244,140.00	14.6	2,534,060.94	Massachusetts
Michigan	16,234,000.80	7,328,316.91	612.6	7,172,875.22	3,284,579.34	272.1	10,732,830.57	4,978,793.08	281.6	501,034.00	208,769.57	11.9	4,541,906.10	Michigan
Minnesota	30,415,685.89	12,738,642.04	2721.2	5,271,152.99	2,284,974.52	397.0	7,588,721.98	2,433,300.00	522.4	669,056.29	123,000.00	37.9	2,011,863.44	Minnesota
Mississippi	10,292,285.79	4,986,702.73	803.4	1,370,556.59	984,316.58	156.9	8,680,615.97	4,251,609.44	427.8	607,557.96	303,778.95	65.0	1,599,610.30	Mississippi
Missouri	17,368,156.57	8,219,411.43	1118.9	4,262,723.91	2,066,541.56	190.3	25,054,337.23	9,853,232.64	698.6	1,095,747.26	31,375.43	29.1	2,615,874.94	Missouri
Montana	10,156,600.41	5,317,523.15	921.6	705,847.87	528,905.67	71.2	1,779,748.42	1,306,965.25	175.2	1,016,469.79	565,015.94	119.0	5,706,474.99	Montana
Nebraska	9,306,374.36	4,389,523.50	1570.6	1,521,442.87	736,793.25	120.3	10,923,742.34	5,410.993.94	1079.6	435,168.68	216,080.08	40.7	3,881,844.23	Nebraska
Nevada	4,917,465.69	3,088,299.78	357.3	1,363,562.91	1,145,956.53	125.6	4,203,299.63	3,507,647.17	367.9				1,053,311.52	Nevada
New Hampshire	4,165,687.86	1,986,226.87	208.1	765,008.74	361,274.93	27.6	648,566.19	304,202.46	19.5	9,979.13	4,989.56	0.5	512,798.18	New Hampshire
New Jersey	11,961,357.45	3,820,679.99	219.1	2,112,044.24	581,403.46	35.1	8,463,105.76	3,079,655.72	56.4				985,680.83	New Jersey
New Mexico	8,717,939.18	4,914,070.61	1081.3	3,545,064.81	2,313,941.49	329.6	1,476,466.48	972,341.77	116.3	74,555.37	46,757.90	5.4	2,725,274.23	New Mexico
New York	28,597,769.67	12,229,076.53	831.5	7,008,005.43	2,846,740.06	175.5	32,436,625.75	9,808,265.30	621.7	3,053,570.00	2,222,840.00	148.6	6,938,273.11	New York
North Carolina	21,014,450.41	8,746,454.59	1119.8	2,964,398.83	1,243,624.94	79.6	8,120,203.86	3,414,734.91	190.1	1,790,503.65	597,253.57	35.0	1,715,137.99	North Carolina
North Dakota	10,829,263.82	5,268,930.47	1917.5	778,568.75	388,974.47	164.5	4,282,459.87	2,143,144.39	533.0	926,305.53	463,152.66	131.0	2,484,457.01	North Dakota
Ohio	41,572,252.81	15,244,993.93	1191.1	4,626,351.05	1,574,690.48	129.7	9,817,054.82	3,843,082.39	306.3	2,077,246.25	669,907.97	57.5	4,399,121.23	Ohio
Oklahoma	20,787,024.94	9,672,890.34	852.2	2,570,086.53	1,194,939.18	112.3	6,364,192.65	3,012,797.46	291.0	719,754.38	227,746.85	20.2	1,951,413.17	Oklahoma
Oregon	14,388,188.70	7,142,364.63	794.6	1,409,879.93	767,336.36	75.3	2,817,306.00	1,644,702.27	144.2	1,536,179.15	118,576.27	42.8	1,206,367.47	Oregon
Pennsylvania	43,054,835.19	16,222,023.97	850.3	4,442,508.99	1,319,739.45	80.9	35,951,160.10	9,744,058.97	663.7	1,829,834.89	600,285.62	44.7	3,452,672.99	Pennsylvania
Rhode Island	2,628,496.20	1,119,688.09	64.8	481,300.30	154,988.63	6.0	2,380,016.40	654,003.63	40.2	263,012.75	63,136.00	4.2	675,753.65	Rhode Island
South Carolina	11,163,347.84	5,121,267.54	1235.9	1,161,737.54	412,561.25	58.6	6,014,054.74	2,827,005.77	345.2	1,913,650.91	573,602.92	78.1	861,086.52	South Carolina
South Dakota	12,091,434.67	5,980,679.00	1447.9	3,089,615.22	1,480,829.11	387.6	5,037,902.24	2,426,523.01	764.4				1,269,558.88	South Dakota
Tennessee	13,789,140.98	6,732,079.77	497.9	3,119,078.93	1,516,196.20	122.7	10,018,067.48	4,472,948.74	316.8	1,318,895.56	621,612.00	58.7	1,937,754.29	Tennessee
Texas	54,120,970.83	21,057,940.12	3907.1	8,890,315.94	3,677,963.16	540.5	20,102,943.89	8,885,378.47	1168.4	4,827,819.52	2,198,083.57	248.5	4,787,065.68	Texas
Utah	6,259,159.41	3,818,836.91	423.1	448,533.65	294,374.47	10.5	2,922,204.30	2,014,512.26	251.9	279,557.40	212,710.59	16.0	1,478,344.77	Utah
Vermont	3,015,174.51	1,452,894.45	107.8	200,295.47	100,082.03	3.5	1,983,964.60	885,348.64	46.2	59,192.10	29,596.05	0.1	800,585.83	Vermont
Virginia	13,099,720.01	6,271,998.20	676.2	6,494,805.76	3,008,514.78	241.3	5,980,342.65	2,623,564.04	195.2	2,177,236.66	971,726.94	52.1	625,710.04	Virginia
Washington	13,352,504.18	6,117,211.87	526.7	3,392,361.37	1,510,538.36	137.0	1,982,719.23	963,400.00	26.7	757,215.96	261,000.00	1.2	1,293,625.77	Washington
West Virginia	7,343,200.86	3,230,293.33	326.7	252,664.30	123,013.89	12.8	7,002,615.99	2,787,834.00	185.7	327,937.93	133,956.79	11.3	1,077,412.99	West Virginia
Wisconsin	21,807,140.91	8,919,640.62	1451.7	1,106,354.69	547,215.65	54.5	5,552,066.62	2,728,635.42	272.1	343,475.86	171,345.00	19.2	5,071,978.31	Wisconsin
Wyoming	8,609,819.33	4,739,096.67	982.0	1,494,137.50	907,603.81	102.8	2,999,872.84	1,877,948.36	208.8	28,580.20	18,348.00	0.1	1,023,277.16	Wyoming
Hawaii							342,277.22	97,440.00	6.5				1,002,713.00	Hawaii
TOTALS	740,140,790.82	325,654,346.00	41898.3	117,469,946.28	53,434,689.49	5920.1	375,377,466.20	159,702,616.03	15421.0	46,639,239.02	16,268,515.36	1893.4	116,314,833.12	TOTALS

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $ 117,419,095.53 Federal aid $ 50,407,812.60 Miles 4583.3